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Assessment of household-level adaptation strategies to water stress in southwestern coastal Bangladesh: a counter-factual analysis

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ABSTRACT

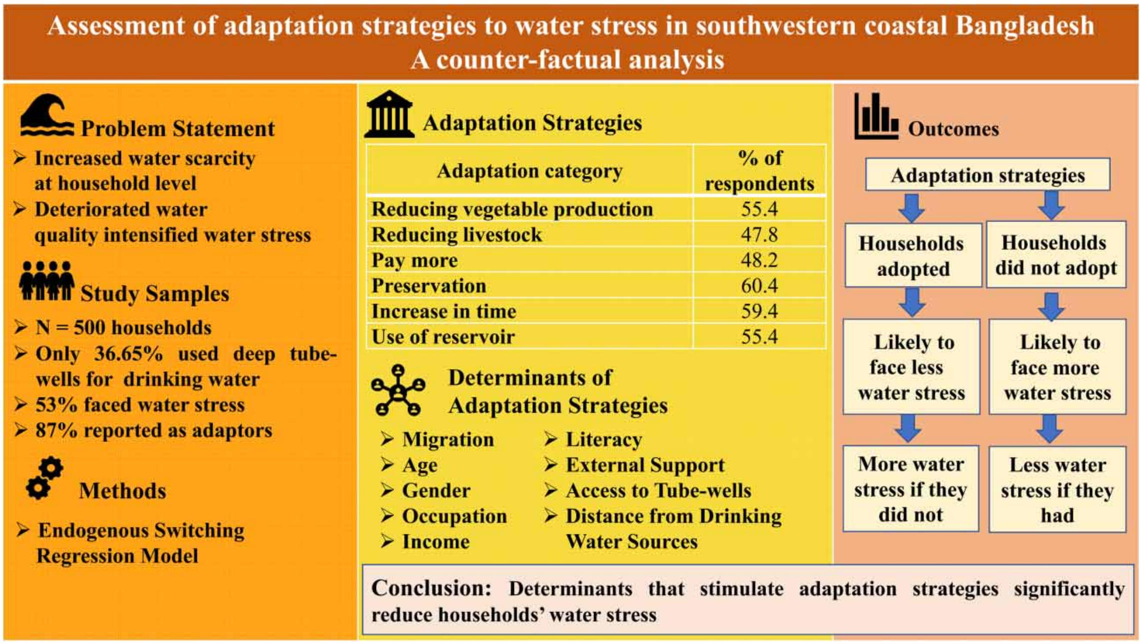
Despite the growing emphasis and global initiatives to ensure safe drinking water and sanitation for all (Sustainable Development Goal 6), households in coastal areas are at risk of growing water stress across the globe. However, little is known about households' adaptation strategies to water stress in coastal areas. This study explores the determinants and impacts of adaptation strategies to household-level water stress (both drinking and non-drinking), considering the behaviors of adopters and non-adopters in the southwestern coastal area of Bangladesh. We applied an endogenous switching regression model by analyzing questionnaire survey datasets ($n=502$) to estimate the effect of adopting adaptation strategies on household-level water stress in four saline-prone coastal sub-districts of Bangladesh. Results reveal six commonly-practiced adaptation strategies: reducing vegetable production, reducing livestock production, paying more to access water, increasing time for water collection, preserving water, and using reservoirs to collect water. Determinants such as migration, support from government and non-government agencies, age, gender, literacy, occupation, income, access to tube wells, and distance from drinking water sources play a significant role in adopting adaptation strategies. Results from the endogenous switching regression model denote that adopting all six adaptation strategies appears to significantly reduce household-level water stress. Through counter-factual analysis, results demonstrate that, on average, households that did not adopt adaptation strategies would have encountered less water stress if they had. Therefore, determinants that stimulate adaptation strategies will indirectly reduce household water stress.

Key words: Adaptation, Bangladesh, Coastal, Counter-factual analysis, Water stress

HIGHLIGHTS

- Six distinct adaptation strategies are identified to withstand water stress.
- Different socioeconomic determinants and migration significantly affected the adoption of the adaptation strategies.
- Endogenous Switching Regression Model is applied.
- Counter-factual analysis presents the difference in treatment effects between adopters and non-adopters of six adaptation strategies.

GRAPHICAL ABSTRACT



1. INTRODUCTION

The water system is part of the complex systems and infrastructure that support all life on earth (Sweya *et al.*, 2018). It supports our lives by providing essential inputs to agriculture, industries, health, social well-being, and the economy (Abedin *et al.*, 2014). Freshwater is crucial for enhancing our health and living standards. Almost 70% of our planet is covered by water, with two-thirds of that water inaccessible to use or frozen in glaciers, and only 3% of that is freshwater (WWF, 2021). The global water demand has been growing at an increasing rate, forecasted to rise by 55% in the next few decades (Abedin *et al.*, 2014; Schlamovitz & Becker, 2021). Around two billion people cannot safely access drinking water, and approximately 2.3 billion people lacked safely managed sanitation in 2020 (UN, 2021a). Every year, millions of people suffer from water-borne diseases such as diarrhea, cholera, typhoid, and parasites (Abedin *et al.*, 2014). For sustainable human development and healthy life, access to adequate and safe drinking water is essential, and it must be available for all (Mustari & Karim, 2016). The United Nations (UN) declared 2018–2028 as the decade for 'Water for Sustainable Development' in its General Assembly on 20–21 December 2018 and listed availability and sustainable water and sanitation management for all among its 17 Sustainable Development Goals (SDGs) (UN, 2021a, 2021c).

Water scarcity and deteriorating water quality are becoming major global concerns (Shamsuzzoha *et al.*, 2018). Problems related to water are most acute and have become a crucial issue for Asian countries (Abedin *et al.*, 2014; Mallick & Roldan-Rojas, 2015; Mustari & Karim, 2016). Water usage has been increasing worldwide at more than twice the population growth rate (UN, 2021d), resulting in acute water stress, especially in developing and agriculture-based countries like Bangladesh (Abedin & Shaw, 2013; Mustari & Karim, 2016). Even before the COVID-19 outbreak, 129 countries were alarmingly off track to achieving sustainable water resources management by 2030, as stipulated in the UN SDGs (UN, 2021a, 2021b). Many coastal areas of the world are exposed to significant water scarcity and have become more vulnerable due to frequent natural and man-made hazards

(Shamsuzzoha *et al*., 2018; Talukder *et al*., 2020). It is estimated that by 2050 more than five billion people would likely suffer from inadequate access to fresh and safe water, while globally, almost 3.6 billion people have already faced water shortage problems since 2018 (Farge, 2021; WMO, 2021). Furthermore, 35 million coastal inhabitants worldwide are confronted with the problem of drinking water supply because of salinity intrusion (Rahman *et al*., 2021). The World Bank reported a 10% increase in migration rate within countries due to water deficits between 1970 and 2000 (World Bank, 2021).

Being a Ganges-dependent region, the coastal region of Bangladesh is susceptible to adverse climatic impacts, including extreme events (Rakib *et al*., 2019). The sufferings of coastal inhabitants are also intensifying because of acute water scarcity and arsenic contamination (Abedin *et al*. 2014). With an estimated 50 million people, Bangladesh is highly exposed to groundwater arsenic contamination at levels above the acceptable limit of 0.05 μg/l (Mallick & Roldan-Rojas, 2015; Ahmad, 2019). Furthermore, salinity intrusion increases the freshwater crisis in coastal areas, making the region more susceptible to climate change impacts (Nahian *et al*., 2018). Saline contaminated water and scarcity of drinking water increase the incidence of high blood pressure, skin diseases, heart and kidney disease, hypertension, and many acute respiratory infections in the coastal region, compared with other regions of Bangladesh (Rakib *et al*., 2019). Besides, around 20 million people in coastal districts and approximately 1.02 million hectares of land in coastal zones of Bangladesh are affected by varying degrees of salinity intrusion (Mallick & Roldan-Rojas, 2015). The decline of ground and surface water at a faster rate than its replenishment ultimately exacerbates the water crisis (Rafa *et al*., 2020). This situation appears to be compounded by existing problems due to frequent disasters and anthropogenic activities (Abedin *et al*., 2014; Talukder *et al*., 2020). Though Bangladesh is a riverine country, the water supply in the dry season is limited, resulting in people being highly dependent on groundwater (Goes *et al*., 2021). Recently, the availability and quality of fresh groundwater have been aggravated by arsenic contamination, salinity intrusion, and inadequate aquifers (Talukder *et al*., 2020). People at risk in coastal Bangladesh largely depend on unimproved surface water (e.g., pond water) for drinking and non-drinking purposes such as cooking, washing, etc. Hence, scarcity and degree of access to freshwater become a challenge for coastal households. This challenge becomes acute in the coastal areas during the dry season when ponds dry up, and households' water stress is intensified by the impairment of their regular domestic activities.

In Bangladesh's coastal aquifers, the upper shallow (or first) aquifer (<90 m) of groundwater is polluted by the varying levels of salinity where potable water may not be available and adequate even at greater depths (Roman *et al*., 2021). As the freshwater aquifers are primarily unavailable at suitable depths in the coastal regions, the availability of a safe drinking water supply system becomes limited (Islam *et al*., 2010). Both deep and shallow tube wells do not work in certain districts of the coastal region because of groundwater contamination by arsenic and saline (Abedin *et al*., 2014). To mitigate water-related challenges, the coastal people at risk generally depend on pond water (known as *mitha pukur*), rainwater harvesting (RWH), or pond-sand-filter (PSF) water to meet their daily required quantity of drinking water and non-drinking water for other domestic utilities (Mallick & Roldan-Rojas, 2015). Though RWH and PSFs have become potential options for safe water supply at the household level in coastal Bangladesh, adoption of these strategies is limited because of low storage capacity and maintenance challenges (Islam *et al*. 2013). However, without any participation of local community and development partners, the establishment of a safe and sustainable water system cannot be possible. The government of Bangladesh takes several initiatives to minimize the water-related challenges (Das Gupta *et al*., 2005). At the national level, the Department of Public Health and Engineering (DPHE) is bound to supply safe drinking water in Bangladesh (Abedin *et al*., 2014). Along with this department, some international donor organizations such as UNICEF, UNDP, and the World Bank have taken small piped-water schemes targeting the safest freshwater sources in coastal areas (Roman *et al*., 2021). At the household level, coastal people have adopted several water-related adaptation strategies based on the availability and usability of water (Islam *et al*., 2013). However, only a handful of studies address adaptation strategies for responding to households' water stress in coastal Bangladesh and the factors affecting those strategies (Kumar *et al*., 2020; Ahsan *et al*., 2021), which implies a knowledge gap. Therefore, this paper aims to address this gap by exploring the determinants and impacts of adaptation strategies for households encountering water stress, considering the behaviors of both adopters and non-adopters of adaptation strategies. In this regard, we first explore the factors of adaptation options to household-level water stress for both drinking and non-drinking purposes; and second, we investigate the impact of different types of adaptation strategies on household-level water stress. We apply the endogenous switching regression model with counter-factual analysis to investigate what households would have faced if they had not adopted a specific adaptation strategy for reducing household-level water stress. In this paper, we operationalize households' water stress as water scarcity triggered socioeconomic and socio-environmental stresses.

In the remainder of this paper, we present a theoretical background in Section 2, methods and materials in Section 3, results and discussion in Section 4, and conclusion in Section 5.

2. THEORETICAL CONSIDERATIONS

The conceptualization of water stress varies from micro-level to macro-level and is related mainly to sustainability and human welfare (FAO, 2022). Water stress is a risk perspective in domestic use but a more inclusive concept (CWM, 2022). Households' water stress can be described as a state of disturbance (i.e., socioeconomic, environmental, or health problems) caused by inadequate quantity and unacceptable quality of water resources, which cannot meet the water demand (EEA, 2022). Facets such as water availability (presence of water), use (acceptability of water), supply (getting required water), and scarcity (lack of freshwater) are equally significant, which causes trouble in featuring water stress levels (Rosinger & Young, 2020).

Presently, one of the most pressing issues is ensuring the availability of a sufficient quantity of safe water for the welfare of human life, which the United Nations implicates in its Sustainable Development Goal (SDG) no. 6 (Young *et al*., 2019). Water availability can be defined as the adequacy of freshwater in response to its demand. In contrast, water scarcity is a shortage of required safe water resources to meet the demand (Damkjaer & Taylor, 2017). According to Rosinger & Young (2020), more than 880 million people have inadequate access to improved drinking water sources globally. Around 4 billion people do not get sufficient water for at least one month in a year. Nearly 97% of the total population of Bangladesh has access to improved water sources, but only 39% of people can manage safe drinking water sources (Hoque *et al.* 2019). This unavailability of safe drinking water resources is explicitly linked with water stress (Damkjaer & Taylor, 2017).

Coastal inhabitants of Bangladesh are the most vulnerable to the adverse hydrological effect of climate-triggered hazards, including tropical cyclones and tidal surges, mainly in the pre- and post-monsoon periods (Hoque *et al*., 2019). Tidal surges and floods inundate water bodies, including ponds and tube wells, significantly distress coastal households because they highly depend on ground and surface water (Abedin *et al*., 2019). Riverbank erosion has a long-term impact by creating heavy loss (losing nearly 8,700 hectares of the homestead and farming land and displacing around two million people annually) (Alam *et al*., 2018). These situations are expected to become more severe due to frequent and heavy rainfall. The monsoonal climate of Bangladesh is responsible for frequent and heavy precipitation resulting in catastrophic floods (Alam *et al*., 2018). In addition, salinity intrusion and arsenic contamination are accountable for the persistent degradation of water quality and infrastructure. Because of freshwater shortage triggered stress, hypertension is increasing more among women than men (Hoque *et al*., 2019).

Besides, the global burden of disease is intensifying because of the problems interlinked with water availability, water accessibility, and water quality (Young *et al.*, 2019; Rosinger & Young, 2020). Though the required amount of water for domestic supply constitutes a small amount of total water withdrawal, inadequate access to domestic water supply can lead to disease. Children are the most prominent victims of poor water quality and sanitation (Howard & Bartram 2003). Households' health risks are considerably increasing due to lower living standards, insufficient water resources, and an unhygienic sanitation system (Pasakhala *et al.*, 2013). Contaminated water causes water-borne diseases such as diarrhea, cholera, and skin diseases, creating high health risks for coastal households of Bangladesh (Abedin *et al.*, 2014; Abedin *et al.*, 2019). Women and children are generally supposed to collect required water for both drinking and non-drinking purposes. Their physical and emotional sufferings are related to going long distances with heavy pots for water collection (Hoque *et al.*, 2019).

In such inescapable conditions, practicing adaptation strategies has increased recognition globally for building resilient capacity and reducing water stress (Alam *et al.*, 2018). Adaptation measures are the planned responses to stand with the shocks and stress in the future. The main component of adopting an adaptation strategy is the household's perception, which influences the adaptation decision of taking or not taking over a long period (Basu *et al.*, 2015). People rely highly on the water for food purposes and health security, and they practice a wide range of adaptation strategies to combat the water crisis (Basu *et al.*, 2015). Strategies like enhancing storage capacity or digging wells are capital-intensive approaches. In contrast, strategies like going long distances to collect water or treating water are labor-intensive, and time-incentive measures reduce water stress in the short run (Hoque *et al.*, 2019).

Considering the discourses mentioned above, in this study, we developed a conceptual framework presented in Figure 1 to display the interconnection between water stress and adaptation strategies at the household level.

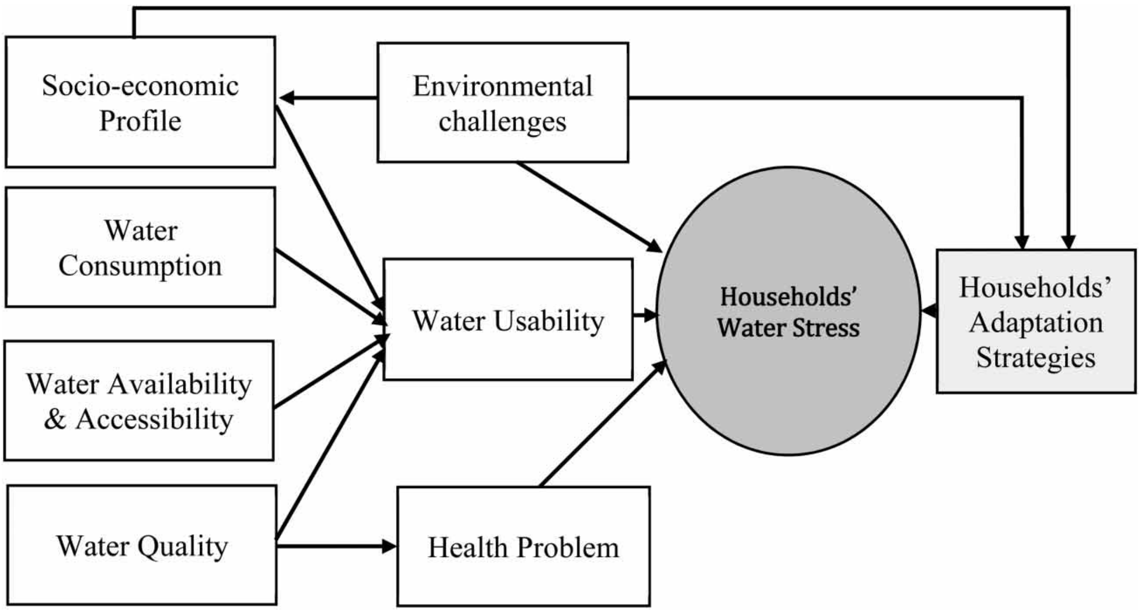


Fig. 1 | The conceptual framework for water stress and adaptation strategies used in this study.

3. METHODS AND MATERIALS

3.1. Study area, sampling strategy, and data collection

We primarily applied three criteria to select the study area: first, the area suffers persistent water crises during the dry season; second, the area significantly depends (directly and/or indirectly) on a mangrove forest for the livelihood of its inhabitants; and third, the area is highly susceptible to natural hazards, especially tropical cyclones, floods, and salinity intrusion. Using these criteria, two districts from the southwestern coastal zone, Khulna and Satkhira, were selected primarily as the broader study locations.

We applied a multistage sampling technique to select the samples for our study. In this regard, after selecting Khulna and Satkhira districts as the broader study locations, in the second stage, we chose from each of these districts four sub-districts that are significantly exposed to extreme climatic events. We selected Batiaghata, Dacope, Dumuria and Koyra sub-districts from Khulna, and from Satkhira, we selected Assasuni, Debhata, Kaliganj, and Shyamnagar sub-districts. From these eight sub-districts, in the third stage, we selected Dacope and Koyra from Khulna and Assasuni and Shyaamnagar from Satkhira by applying a lottery method. We again applied a lottery method in the fourth stage and selected 16 villages from these four sub-districts, as presented in Figure 2.

In the final stage, to select the household respondents, we could not perform a purely random sampling (according to the list prepared by the election commission office) as the whole coastal region was hit by super

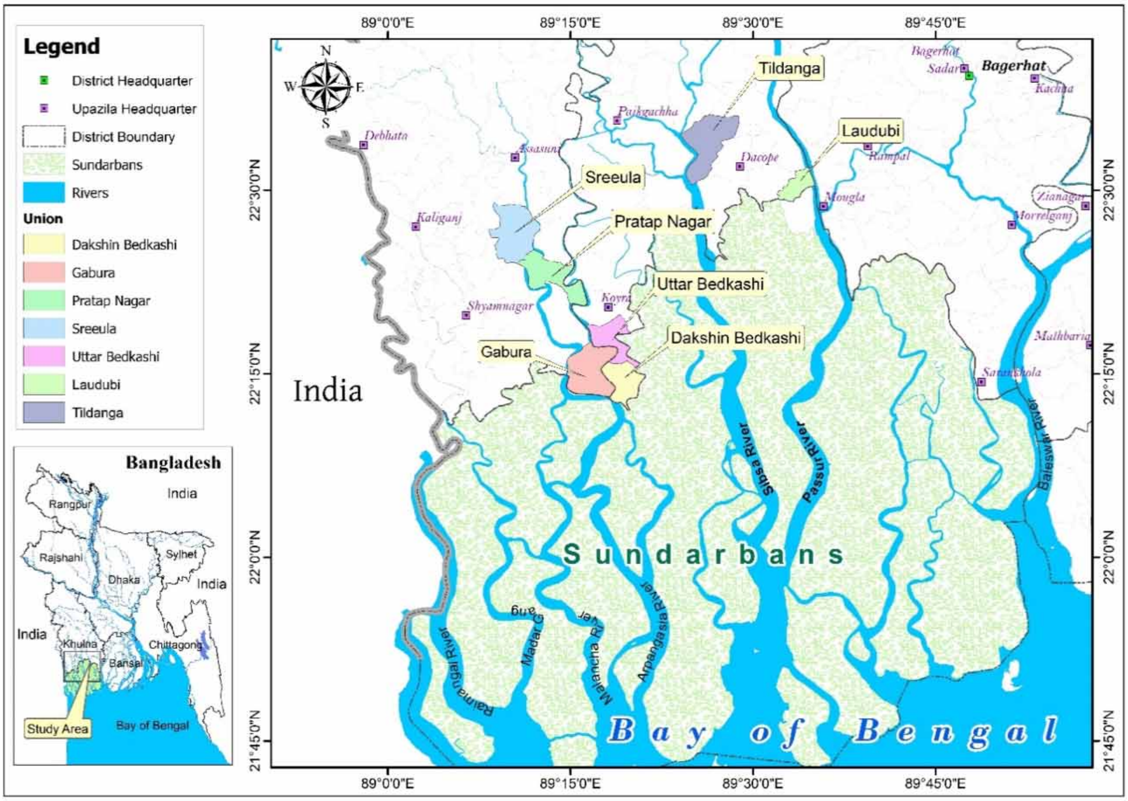


Fig. 2 | Locations of study areas. *Source*: HDX (2020).

cyclone Amphan in May 2020, causing the relocation of millions of people at risk. Under the circumstances, we applied a systematic random sampling to select 502 respondent households from 16 villages. We chose every seventh household along the road (alternatively from both right and left sides) connecting the central business point with the village.

The questionnaire used for this study consisted of 59 closed-ended questions, which were selected through several phases to address social-demographic-economic profiles and water-related aspects, namely water quantity, water quality, water security, and water stress-related issues. In the first phase, a draft questionnaire was prepared based on inputs provided by participants of four Focus Group Discussions (FGDs) in different sub-districts. In the second phase, a pilot survey was performed with the respondents in several villages of these four sub-districts. Based on the feedback from the piloting, we incorporated necessary modifications in the draft questionnaire. Thus, the final version of the questionnaire for a face-to-face household survey was prepared. Data collection was administered using this questionnaire from May to July 2021 in different study locations. Senior undergraduate university students with experience in performing questionnaire surveys were deployed for data collection. The head of a household of at least 20 years old was considered as the respondent during data collection. If enumerators could not reach the head of the household for the interview, they interviewed any other adult member who often participates in the household decision-making process.

3.2. Analytical approach

3.2.1. Calculation of household level water stress index

Water stress accounts for water scarcity-induced social, economic, and/or environmental stresses. However, it is challenging to characterize water stress, as several facets are pertinent to water availability, supply, and quality. In this study, we adapted and customized the formation of the water stress index based on the approach used by Zhao *et al*. (2011) and Alam *et al*. (2018). Based on the literature in Section 2, we selected the variables for our customized water stress index, where these variables were considered under dimensions, namely water usability, health problems, environmental challenges, and coping strategies to deal with water shortage (mentioned in the theoretical framework in Figure 1). Table 1 presents a list of 29 variables used to prepare this index.

We considered a standardized index value for each indicator where the index value was calculated by following the formula $I_{iv} = I_i - I_{min}/I_{max} - I_{min}$, where I_{iv} represents the index value of indicator I, I_i denotes the actual value of indicator I, I_{max} represents the highest value of indicator I in the concerned series, and I_{min} denotes the lowest value of indicator I in the series. The range of the standardized index value lies between 0 and 1. If the index values of water usability (WU) and coping strategies (CS) are closer to 1, it will reduce the value of WSI. Conversely, if the index value of environmental challenges (EC) and health problems (HP) are closer to 1, it will increase the value of WSI. Ultimately, a higher index value of WSI indicates a household with a higher degree of water stress.

3.3. Empirical analysis

Applying an ordinary least square (OLS) regression model to observe the impact of adopting adaptation strategies to household-level water stress would likely provide a biased estimation. Adopted adaptation strategies under standard settings are usually self-selected by the households based on their expected benefits (Asfaw & Shiferaw, 2010). Different characteristics of those households that adopted them may differ systematically from those households that did not adopt them. Besides, self-selection of adaptation strategies may result in an endogeneity problem (Alene & Manyong, 2007). Furthermore, households' unobservable features (i.e., innate abilities) are more likely to affect their adoption decision and level of water stress. These unobservable features are highly likely to provide inconsistent estimates of the effect of adaptation strategies on household-level water stress

Table 1 | Components and indicators comprising the household water stress index (WSI).

Components	Indicators	Expectations
Water Usability (WU)	1. Male-female ratio 2. Household Size 3. Dependency Ratio 4. Per capita quantity of daily drinking water 5. Per capita quantity of daily water requirement for non-drinking purpose 6. Number of times household collect drinking water per week 7. Time required to collect drinking water from the source 8. Time required to collect water (required for non-drinking purpose) from the source 9. Times of facing difficulties to collect water 10. Changing water sources because of unsafe drinking water in past twelve months 11. The household or the nearby community own any water preservation reservoirs 12. Satisfaction level about water quality 13. Use of averting strategy for purifying water 14. Cost of treatment per month 15. Times of treating water in a week	Increased water usability will reduce household level water stress.
Coping Strategies (CS)	16. Number of coping strategies taken in the dry season	No. of effective coping strategies will reduce household's stress on water.
Environmental Challenges (EC)	17. Losing homestead because of flash flood 18. Losing homestead because of riverbank erosion 19. House flooded due to heavy rain 20. Losing crops because of too much rain/flood 21. Frequency of rainfall over the last decade 22. Intensity of rainfall over the last decade 23. Duration of rainfall over the last decade 24. Off-season rainfall over the last five years 26. Changes in temperature have impacts on ground water level	Water related environmental problems will increase stress on water.
Health Problems (HP)	27. Become sick because of unsafe water 28. Facing water borne disease 29. Steps taken while feeling sick or facing the water borne diseases	Health Problems due to unsafe water (HP) will increase household's water stress.

(Tesfay, 2020). Moreover, OLS cannot address counter-factual issues (e.g., effects of adoption by non-adopters and effects of non-adoption by adopters) during impact evaluation under quasi-experiment studies. Therefore, these limitations of OLS cannot help account for the actual effect of an adaptation strategy on household-level water stress.

For this reason, we employed the endogenous switching regression model (ESR), which estimates the effect of adopting adaptation strategies on household-level water stress by addressing sample selection, unobservable features, and endogeneity problems. ESR, a two-stage estimation-based parametric approach, can control the effects of all observed and unobserved variables that influence both adoption and outcome variables in the quasi-experimental setting (Khanal *et al*., 2018). This model involves a selection equation and two continuous regressions (Sarma & Rahman, 2020). In the first stage, adopting adaptation measures as a selection equation is estimated using a standard binary regression method (i.e., binary Probit model). In the second stage, household-level water stress (outcome variable) is modeled for both adopters and non-adopters conditional on selection to assess the effect of adoption of adaptation (selection variable) on household-level water stress (outcome variable).

ESR, which is based on expected utility maximization theory, lays the foundation to estimate the effect of the adoption of a strategy by maximizing its utility and comparing the maximized utility provided by different adaptation strategies (Sileshi *et al*., 2019; Sarma & Rahman, 2020). Adopting an adaptation strategy is a dichotomous choice, where an individual decides to adopt an adaptation strategy if the expected outcome from the adaptation strategy is greater than the expected outcome of not adopting that strategy. Following Khanal *et al*. (2018), a rational individual *i* is likely to adopt a particular adaptation strategy if the expected level of water stress from adoption (W_{Ai}) is less than the level of water stress from non-adoption (W_{Ni}) (i.e., $W_{Ai}<W_{Ni,}$ where $A\neq N$).

The adoption decision (A) is a dichotomous choice where A=1 if W_{Ai} $<W_{Ni}$ and A=0 if otherwise. A researcher does not observe the expected level of water stress from adaptation strategies but can observe the adoption of adaptation strategies. A latent variable can represent the outcome derived from the adoption of adaptation strategies A_i^*. It can be expressed as a function of the observed households' characteristics and attributes that influence adoption of the adaptation strategies:

$$A_i^* = \mathrm{X_i}\beta + \mu_\mathrm{i} \text{ with } A_\mathrm{i} = \begin{cases} 1 \; if \; A_i^* \; > 0 \\ 0 \; if \;\; A_i^* \; \geq 0 \end{cases} \tag{1}$$

where β is a vector of unknown parameters to be estimated, and μ is a random error term with mean zero and variance. The error term includes measurement error and factors not observed by the researcher but known to the household. X is the vector of households' characteristics and attributes regarding adopting the adaptation strategies. Variables in X include measures of age, gender, education, religion, occupation, standardized male-female ratio, standardized dependency ratio, household size, income, distance from drinking and non-drinking water sources, access to tube wells, support from government and non-government organizations, migration, homestead damage due to flood and riverbank erosion, and study locations (i.e., union). We also included climatic variables such as a significant change in frequency, intensity, and duration of rains. We used Probit maximum likelihood estimation to estimate the parameter β in Equation (1).

Adoption of adaptation strategies affects the household level of water stress. In the second stage, separate outcome equations are specified for adopters and non-adopters. Let $W=f(Z)$ represent the relationship between a decision variable W (e.g., household water stress) and a vector of exploratory variable Z:

$$W_{Ai} = Z_{Ai}\delta_A + \varepsilon_{Ai} \; if \; A_i = 1 \tag{2a}$$

$$W_{Ni} = Z_{Ni}\delta_N + \varepsilon_{Ni} \; if \; A_i = 0 \tag{2b}$$

where W_{Ai} and W_{Ni} are the level of water stress specified for adopters and non-adopters, respectively. Z is a vector of household socioeconomic characteristics that affect the level of water stress included in X. δ_A and δ_N are vectors of parameters to be estimated. However, according to Sileshi *et al*. (2019), if the selection equation of the first stage was endogenous in the outcome equation of the second stage, findings would be inconsistent and biased. Instrumental variables are used to identify the second stage equation from the first stage equation. The instrumental variables should affect the adoption of adaptation strategies only and not the level of water stress. Therefore, at least one variable that affects the adoption decision but not the outcome variable must be included in the adoption equation but excluded from the outcome equation to identify the model (Di Falco *et al.*, 2011). This study used climatic information such as a significant change in frequency, intensity, and rainfall duration for the instrumental variables. These variables are expected to affect adoption decisions but not directly affect the water stress level.

Furthermore, the endogenous switching regression (ESR) method addresses counter-factual problems by comparing adopter households' expected level of water stress with non-adopter households' expected level of water stress for both observed and unobserved samples. The expected level of water stress of both adopters and non-adopters in observed and counter-factual cases are given as follows:

Adopters with adoption (observed in the sample):

$$E[W_{Ai}|A_i = 1] = Z_{Ai}\delta_A + \sigma_{A\mu}\lambda_{Ai} \tag{3a}$$

Non-adopters without adoption (observed in the sample):

$$E[W_{Ni}|A_i = 0] = Z_{Ni}\delta_N + \sigma_{N\mu}\lambda_{Ni} \tag{3b}$$

Non-adopters had decided to adopt (counter-factual):

$$E[W_{Ni}|A_i = 1] = Z_{Ai}\delta_N + \sigma_{N\mu}\lambda_{Ai} \tag{3c}$$

Adopters had decided not to adopt (counter-factual):

$$E[W_{Ai}|A_i = 0] = Z_{Ni}\delta_A + \sigma_{A\mu}\lambda_{Ni} \tag{3d}$$

In this study, the average treatment effect on the treated (ATT) is the change in household-level water stress due to the adoption of adaptation strategies which can be computed from Equations (3a) and (3c) as:

$$\text{ATT} = E[W_{Ai}|A_i = 1] - E[W_{Ni}|A_i = 1] = Z_{Ai}\ (\delta_A - \delta_N) + (\sigma_{A\mu} - \ \sigma_{N\mu})\ \lambda_{Ai} \tag{4}$$

Similarly, the average treatment effect on the untreated (ATU) can also be calculated by comparing the expected household-level water stress of non-adopters in real and counter-factual scenarios from Equations (3b) and (3d) as:

$$\text{ATU} = E[W_{Ni}|A_i = 0] - E[W_{Ai}|A_i = 0] = Z_{Ni}\ (\delta_N - \delta_A) + (\sigma_{N\mu} - \ \sigma_{A\mu})\ \lambda_{Ni} \tag{5}$$

We repeated the above process six times to estimate the effect of six different types of adaptation strategies on household-level water stress. We performed all quantitative analyses using a statistical package called Stata (version 17).

4. RESULTS AND DISCUSSION

4.1. Socioeconomic characteristics

Table 2 presents the major socioeconomic characteristics of the sample respondents of this study. The majority (87%) of the respondents were male. The age pattern shows that most of the respondents were in middle age, as the average age of the respondents is estimated at 43.17 (±10.69) years. The average household size is found to be 4.69 (±2.08) persons, which is slightly higher than the average household size in the Khulna division (4.0 persons) (BBS, 2019). A similar trend is also seen in the male-female ratio. The average male-female ratio among households in the study area is 1.146, while the average male-female ratio in the Khulna division is 1.014 (BBS, 2019). Among the respondent households, the dependency ratio is estimated at 0.34 (±0.28). Literacy status suggests that, on average, the respondent households had completed 5.42 (±3.94) years of schooling, implying that the academic achievement of this study area was not satisfactory. Only 2.49% of the total respondents had completed graduation. Most of the respondents (96.21%) were married, and three-quarters of the respondents were Muslim. Nearly 15% of the respondents were unemployed (i.e., having no paid job). However, many people were day laborers (37.25%). Besides, more than one-third of the respondents were engaged in diversified agricultural occupations such as farmers (8.37%), fishermen (15.54%), vegetable sellers (0.20%), shrimp cultivators (8.37%), and shrimp fry collectors (0.20%). Results suggest that before tropical cyclone Amphan, the standard deviation of the average monthly income was higher than the average monthly income, implying substantial income disparity among respondents' monthly income. Owing to the adverse effects of cyclone Amphan, respondents' average monthly income was reduced to 80%, with nearly 2.6 times lower standard deviation than the previous period. However, respondents' average monthly expenditure was lower than their average monthly income, implying a positive saving possibility. However, comparing the average expenditure with the cost of basic needs, more than one-third of the respondents appeared to be living below the poverty threshold level (35.86% before cyclone Amphan and 37.25% after cyclone Amphan).

Estimations in Table 2 suggest that a respondent's average daily drinking water consumption is four liters, and the average daily water use for non-drinking purposes is nearly 8 liters. About 91% of the respondents used protected wells (54.38%) and deep tube wells (36.65%), and only 3.59% of the respondents used unprotected wells for collecting drinking water, which shows a different scenario from the division-wise report provided by the Bangladesh Bureau of Statistics (BBS, 2019). The BBS report stated that 89% of people collect drinking water from the tube wells, 4.8% from the tap, and only 1% from wells (BBS, 2019). On the other hand, for non-drinking purposes, though more than one-third of the respondents collected water from protected wells, nearly half of the respondents used unsafe water sources such as ponds (38%) and unprotected wells (11%). Table 2 suggests that, as people used more safe water sources for drinking purposes than non-drinking purposes, they had to go far away from their households and spend more time collecting drinking water than collecting non-drinking water. More than half of the respondents stored water for drinking and cooking purposes. However, on average, people had trouble collecting water twice ((±6.5) in the last two years and changed their primary water source 0.61 (±1.91) times in the last year. Besides, only 6% of the total respondents had a wastewater drainage system. Around 68% of the sampled respondents threw wastewater out in front of their house, and 40% threw it out in the back of their house. The results suggested that more than half of the respondents (53%) reported facing water stress problems at household level in the dry season.

4.2. Adaptation strategies

Table 3 represents six household adaptation strategies to reduce water stress as identified by this study, where slightly over 76% of the respondents had taken at least one adaptation strategy to reduce water stress at the

Table 2 | Summary statistics of major socioeconomic characteristics of the respondents.

Households' characteristics	Units of Measurement	N	Value (SD)* [Min-Max]*
Age	Years	502	43.17 (±10.69) [21–82]
Household Size	Number	502	4.69 (±2.08) [2–14]
Male-female ratio	Number	502	1.146 (±0.48) [0.16–3]
Dependent ratio	Number	502	0.34 (±0.28) [0–1.5]
Schooling	Years	502	5.42 (±3.94) [0–17]
Marital status			
Unmarried	Percentage (%)	10	1.99
Married	Percentage (%)	483	96.21
Others (divorced, separated)	Percentage (%)	9	1.80
Employment status			
Unemployed	Percentage (%)	73	14.54
Employed	Percentage (%)	429	85.46
Monthly income before the cyclone Amphan	Thousands in BDT	502	12.21 (±15.33) [0–250]
Monthly income after the cyclone Amphan	Thousands in BDT	502	9.99 (±5.76) [0–80]
Monthly expenditure before the cyclone Amphan	Thousands in BDT	502	8.55 (±3.57) [2–39.8]
Monthly expenditure after the cyclone Amphan	Thousands in BDT	502	8.67 (±4.36) [2–69.8]
Quantity of drinking water	Liters per capita	502	4.15 (±1.29) [1.40–8.75]
Quantity of non-drinking water	Liters per capita	502	7.79 (±4.11) [1.25–22.5]
Source of Drinking Water			
Unprotected well (%)	Percentage (%)	18	3.59
Protected well (%)	Percentage (%)	273	54.38
Deep tube-well (%)	Percentage (%)	184	36.65
Other (%)	Percentage (%)	27	5.38
Source of Non-drinking Water			
Unprotected well (%)	Percentage (%)	55	10.96
Protected well (%)	Percentage (%)	180	35.86
Deep tube-well (%)	Percentage (%)	76	15.14
Pond (%)	Percentage (%)	189	37.65
Other (%)	Percentage (%)	2	0.4
Distance to the drinking water source	Kilometers	502	0.55 (±0.86) [0–4]
Distance to the non-drinking water source	Kilometers	502	0.11 (±0.20) [0–2.5]
Times required to collect drinking water	Minutes	502	19.50 (±23.27) [0–180]
Times required to collect non-drinking water	Minutes	502	6.58 (±6.30) [0–30]
Times of changing primary water source in past 12 months	Number	502	0.61 (±1.91) [0–30]
Times of facing difficulties to collect water in last 2 year	Number	502	2.56 (±6.5) [0–80]

(*Continued.*)

Table 2 | Continued

Households' characteristics	Units of Measurement	N	Value (SD)* [Min-Max]*
Water Storing Purpose			
Drinking	Percentage	283	56.49
Cooking	Percentage	269	53.59
Domestic	Percentage	176	35.20
Livestock	Percentage	174	34.66
Having wastewater drainage system	Percentage	31	6.18

*where applicable.

Table 3 | Different adaptation strategies adopted by respondent households.

Adaptation category	Description of Adaptation strategy	Percentage of respondents
Reducing vegetable production	Reducing vegetable growing during dry seasons	55.4
Reducing livestock	Reducing livestock production when required water becomes unavailable	47.8
Pay more	Paying more to access water when required water becomes unavailable	48.2
Preservation	Preserve drinking and non-drinking water during dry seasons	60.4
Increase in time	Increasing time for drinking and non-drinking water collection	59.4
Use of reservoir	Using water preservation reservoirs for drinking and non-drinking water	55.4

household level. Our estimation showed that nearly 60% of the sampled households preserved drinking and non-drinking water and increased the time for drinking and non-drinking water collection during dry seasons. Nearly 55% of the households adjusted by reducing vegetable growing and water preservation reservoirs for drinking and non-drinking water during dry seasons. Only 48% of the total respondents reduced livestock production and showed a willingness to pay more for access to water as their adaptation strategies.

4.3. Determinants of adaptation strategies to household-level water stress

Table 4 presents an estimation by applying a Probit regression model of the determinants of adoption of six adaptation strategies: reducing vegetable production, reducing livestock rearing, paying more for access to water, increasing time to collect water (both drinking and non-drinking), preserving water, and using reservoirs to lessen household water stress. Two observations in the sample were found as outliers and thus discarded for regression analysis. The summary statistics of the variables used for this Probit regression are presented in Tables A-1 and A-2 in the Appendix. This study identified migration as one of the influential determinants exhibiting a statistically significant and positive relationship for all adaptation strategies with water stress, though only 7.39% of the households migrated due to water stress (Table 4, row 22). This implies that households who have already migrated due to water stress are more likely to adopt adaptation strategies to minimize water stress.

Receiving support from government organizations (GOs) and non-government organizations (NGOs) plays a vital role in reducing water stress for all adaptation strategies except 'preserve water' (Table 4, row 21). Households who receive external (financial or non-financial) support are less likely to reduce vegetable and livestock production, increase water collection time and use water reservoirs, but are more likely to pay more to get

Table 4 | Probit models for adaptation strategies to household level water stress.

		Adaptation strategies					
Row No.	Variables	Reducing vegetable	Reducing livestock	Pay more	Increase time	Preserve water	Reservoir
1	Age (Base ≤30 years)						
2	31 to ≤40 years	0.159 (0.191)	−0.061 (0.274)	0.474** (0.229)	0.001 (0.209)	−0.239 (0.185)	0.180 (0.245)
3	41 to ≤50 years	0.244 (0.196)	−0.087 (0.331)	0.594*** (0.224)	0.262 (0.223)	0.159 (0.213)	0.606** (0.268)
4	Above 50 years	0.207 (0.224)	−0.049 (0.253)	0.266 (0.224)	0.154 (0.236)	0.165 (0.239)	0.721** (0.282)
5	Gender (Male=1; otherwise=0)	0.521* (0.302)	1.023*** (0.348)	0.093 (0.279)	−0.255 (0.252)	0.035 (0.319)	−0.093 (0.293)
6	Religion (Muslim=1; otherwise=0	0.249 (0.190)	0.140 (0.176)	−0.223 (0.146)	0.018 (0.176)	−0.078 (0.182)	0.025 (0.156)
7	Literacy level (Base: Illiterate)						
8	Illiterate to below primary	0.217 (0.247)	−0.311 (0.259)	0.272 (0.208)	−0.328* (0.199)	0.273 (0.244)	0.246 (0.214)
9	Primary to below secondary	−0.116 (0.191)	−0.293 (0.193)	0.416** (0.165)	−0.024 (0.164)	−0.058 (0.171)	0.123 (0.183)
10	Secondary or above	−0.383 (0.262)	−0.619*** (0.216)	0.354 (0.222)	−0.183 (0.195)	−0.060 (0.228)	0.071 (0.211)
11	Employment status (Base: Unemployment)						
12	Farmer	−0.140 (0.321)	−0.492 (0.376)	0.507* (0.285)	0.205 (0.275)	0.617* (0.360)	0.372 (0.323)
13	Day laborer	−0.217 (0.316)	−0.333 (0.348)	0.261 (0.265)	0.145 (0.261)	0.334 (0.361)	0.139 (0.302)
14	Business/service/others	−0.289 (0.389)	−0.418 (0.453)	0.731** (0.350)	0.138 (0.326)	0.386 (0.400)	0.050 (0.452)
15	Standardized male female ratio	0.151 (0.360)	−0.619 (0.462)	−0.147 (0.390)	−0.120 (0.355)	−0.624 (0.456)	−0.310 (0.343)
16	Standardized dependency ratio	−0.071 (0.594)	0.813 (0.563)	0.163 (0.477)	0.800* (0.441)	−0.228 (0.593)	−0.167 (0.554)
17	Household size	−0.072 (0.046)	−0.078 (0.049)	−0.042 (0.045)	−0.053 (0.034)	0.018 (0.051)	0.007 (0.052)
18	Distance from drinking water sources (meters)	0.009 (0.010)	−0.004 (0.010)	0.085*** (0.015)	0.028** (0.012)	0.019* (0.011)	0.020** (0.008)
19	Distance from non-drinking water Sources (meters)	0.039 (0.034)	0.034 (0.035)	−0.023 (0.045)	−0.034 (0.035)	0.074 (0.059)	0.110* (0.063)
20	Access to tube-well (Yes=1; otherwise=0)	0.297 (0.204)	−0.163 (0.177)	−1.003*** (0.149)	−0.400*** (0.139)	−0.554*** (0.173)	−0.498** (0.215)
21	Support from GOs and NGOs (Yes=1; otherwise=0)	−0.848*** (0.228)	−0.627*** (0.220)	0.581*** (0.197)	−0.308* (0.161)	−0.245 (0.227)	−0.448* (0.260)

(*Continued.*)

Table 4 | Continued

Row No.	Variables	Adaptation strategies: Reducing vegetable	Reducing livestock	Pay more	Increase time	Preserve water	Reservoir
22	Migration (Yes=1; otherwise=0)	0.551* (0.281)	0.802** (0.324)	0.719** (0.297)	0.669** (0.303)	0.998*** (0.349)	1.395*** (0.265)
23	Homestead damage due to flood (Yes=1; otherwise=0)	0.048 (0.186)	−0.067 (0.198)	0.137 (0.152)	−0.271 (0.241)	0.158 (0.207)	0.590*** (0.193)
24	Homestead damage due to riverbank erosion (Yes=1; otherwise=0)	0.427* (0.236)	0.282 (0.203)	0.004 (0.187)	0.202 (0.246)	−0.122 (0.191)	−0.303* (0.182)
25	Monthly income (in '000 BDT)	−0.036** (0.017)	−0.054*** (0.015)	−0.024 (0.016)	−0.016 (0.011)	−0.057*** (0.020)	−0.060*** (0.020)
26	Union (Base: Dakshin Bedkashi)						
27	Gabura	0.497*** (0.191)	0.163 (0.175)	0.383* (0.213)	0.444** (0.198)	0.839*** (0.239)	0.681*** (0.211)
28	Laudob	1.048** (0.481)	0.223 (0.501)	−0.076 (0.425)	−0.273 (0.388)	2.251*** (0.469)	0.034 (0.411)
29	Protapnagar	−1.619*** (0.360)	−2.997*** (0.483)	−0.489 (0.348)	−1.709*** (0.283)	−0.361 (0.354)	−1.813*** (0.426)
30	Sreeula	−0.876*** (0.293)	−1.364*** (0.300)	0.006 (0.279)	0.205 (0.280)	0.736** (0.326)	−0.706** (0.319)
31	Tildanga	−1.892*** (0.367)	−1.523*** (0.372)	−0.945*** (0.300)	−0.586* (0.334)	0.193 (0.374)	−0.371 (0.367)
32	Uttar Bedkashi	0.149 (0.209)	0.116 (0.233)	−0.224 (0.210)	0.031 (0.227)	0.240 (0.276)	−0.068 (0.206)
33	Change in rain's frequency*	−0.567** (0.267)	−0.487* (0.259)	−0.559** (0.276)	−0.310*** (0.088)	−0.060 (0.350)	−0.339 (0.318)
34	Change in rain's intensity*	−0.022 (0.290)	−1.190*** (0.366)	−1.053*** (0.156)	−0.385 (0.270)	−0.254 (0.273)	−0.358 (0.251)
35	Change in rain's duration*	−0.829*** (0.128)	0.105 (0.406)	0.439** (0.211)	−0.533** (0.267)	−0.547** (0.215)	−0.331 (0.257)
36	Constant	1.599 (0.000)	2.539 (0.000)	0.318 (0.000)	1.977 (0.000)	1.099 (0.000)	1.204 (0.000)
37	Observations	500	500	500	500	500	500

Standard errors in parentheses.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.
*Likert Scale: 0=No change; 1=Slightly change; 2=Moderately change; 3=Change; 4=Significant change.
We discarded two observations due to missing values from our total samples.

easy and convenient access to water. Therefore, external support (from GOs and NGOs) helps households figure out alternative options instead of reducing economic activities, increasing water collection time, and using water reservoirs. Only less than one-fourth of the respondent households received the support mentioned above.

Among household characteristics, 'distance of the households from drinking water sources' has a significant positive effect on adopting adaptation measures such as paying more, increasing time, preserving water, and using reservoirs. This finding implies that households far away from drinking water sources are more likely to choose adaptation measures to reduce household water stress (Table 4, row 18). These are reflected through 'Water availability and accessibility' in the theoretical framework in Figure 1. However, distance from drinking water sources is significantly associated with reducing vegetable production- and livestock rearing-related adaptation strategies.

Meanwhile, households' access to tube wells has a negative and significant association with non-production-related adaptation measures similar to the 'distance of the households from drinking water sources' (Table 4, row 20). This suggests that households having more access to tube wells are less likely to pay more to access water, spend less time collecting water, and are less likely to preserve water and use reservoirs. More than half of the respondent households (54%) had access to tube wells to collect water, and efforts to expand the tube well coverage would help reduce water stress in the study area. These issues are exhibited in 'Water availability and accessibility' in the theoretical framework in Figure 1. However, access to tube wells does not significantly affect vegetable production reduction and livestock production reduction adaptation strategies (Table 4, row 20), suggesting that expanding tube well coverage might not help households avoid adopting agro-production reduction strategies to reduce water stress.

The coefficient 'monthly income' also significantly negatively affects adaptation strategies such as reducing vegetable production, reducing livestock-rearing, preserving water, and using reservoirs (Table 4, row 25). Results suggest that households with sufficient income to overcome water stress were less likely to reduce vegetable cultivation and livestock rearing. In addition, these households with higher income were also less likely to preserve water and use water preservation reservoirs (Table 4, row 25). This issue is demonstrated through the 'Socioeconomic profile' in the theoretical framework in Figure 1. However, household income does not significantly affect paying more and increasing the time to access water. This finding suggests that high-income households might have adopted alternative adaptation strategies other than the adaptive strategies considered in this study to reduce water stress.

Our findings suggest that perception of the change in rainfall frequency, intensity, and duration significantly influenced four out of the six adaptation strategies (Table 4, rows 33–35). Changes in rain frequency had a negative effect on adopting four adaptation strategies, implying that households who perceived significant changes in the frequency of rainfall were less likely to reduce vegetable production and livestock-rearing. The likelihood of paying more to access water and increasing the time to collect water appeared to be reduced due to this perception (Table 4, row 33). Results using other climatic variables suggest that households who perceived a change in the intensity of rains were less likely to reduce livestock rearing and pay more to access water (Table 4, row 34) and that households who perceived a change in the duration of rains were less likely to reduce vegetable production, increase time to collect water, and preserve water, but more likely to pay more to access water (Table 4, row 35) (also reflected in the theoretical framework in Figure 1). Plausible reasons behind the outcomes from these two climate variables might be that households who perceived significant rain changes were less likely to reduce their production (i.e., vegetables and livestock). They might believe that reducing their production would not minimize the adverse impact of water shortages. Thus, they might depend on irrigation facilities for vegetable production. However, they were also less likely to pay more or spend more time collecting water.

Our empirical results show that adaptation strategies were also location-specific. Results suggest that the likelihood of adopting adaptation strategies was found more in Gabura union (Table 4, row 27) and less in Protapnagar and Sreeula unions of Satkhira district (Table 4, rows 29 and 30) compared to Dakshin Bedkashi union of Khulna district. Again, households of Tildanga union (Table 4, row 31) of Khulna district were less likely to employ adaptation measures than those of Dakshin Bedkashi union of Khulna district. However, respondent-households in Laudob union (Table 4, row 28) of Khulna district were more likely to reduce vegetable production and use water reservoirs to reduce water stress.

Additionally, some household characteristics such as age, gender, education, and occupation had a negligible effect on adopting adaptation measures (also mentioned in the theoretical framework in Figure 1). Findings suggest that respondents in the age group over 30 years but less than 50 years were more likely to pay more to access water (Table 4, rows 2 and 3). Again, respondents over 40 years were more likely to use a reservoir to lessen water stress (Table 4, rows 3 and 4). Male respondents were more likely to reduce their vegetable and livestock production due to water shortage (Table 4, row 5). Probably, they searched for alternative earning sources to reduce the impact of water stress. Farmers were more likely to pay more for access to water and use a reservoir to moderate water stress (Table 4, row 12).

4.4. Impact adaptation strategies to household-level water stress

We applied endogenous switching regression models to control for unobservable selection bias in observing the impact of various adaptation strategies on household-level water stress. Table 5 presents the results of the endogenous switching regression related to the impact of adaptation strategies on household-level water stress. The results show that many of the observed covariates significantly determine household-level water stress for both adopters and non-adopters and that unobserved factors as covariance terms for adopters (ρ_A) and non-adopters (ρ_N) are statistically significant for several adaptation strategies. Thus, our findings suggest that both observed and unobserved factors influence the decision to adopt different adaptation strategies and implement those strategies according to the adoption decision.

In addition, the findings demonstrate the role of self-selection in adoption decision-making. Thus, the implementation of adaptation measures might not have had the same effect on the non-adopters if they had decided to adopt. The statistically insignificant covariates for non-adopters suggest that, in the absence of adoption of adaptation strategies, there would be no significant difference in the average behavior of the said groups caused by unobserved factors. However, the positive sign for ρ_A implies a negative selection bias, suggesting that households with lower water stress than the mean level have a lower probability of adopting adaptation measures. Thus, comparison between the said groups tends to show a significant role in determining adaptation decisions and their performance.

Table 6 presents the level of household water stress under different states of adaptation measures. Columns 5 and 6 of Table 6 present the impact of each adaptation strategy at the level of household water stress, which is the treatment effect. The treatment effect is calculated as the difference between columns 3 and 4. Results notably suggest that the impact of each adaptation strategy on the level of household water stress is statistically significant at the level of 1%.

The expected level of water stress in households that decided to reduce vegetable production is approximately 0.49 points, compared to 0.58 points for the non-adopters of this adaptation strategy. This indicates that households with reduced vegetable production experienced about 16% less water stress than those who did not. Similarly, those who decided to reduce livestock production and pay more to access water experienced about 11 and 9% less water stress than those who did not. On the other hand, the observed effect of water preservation, increase in water collection time, and use of reservoirs is negligible.

However, the counter-factual analysis shows that the effect of adopting these adaption strategies is much larger than the observed effects. The findings from treatment on the treated (TT) analysis show that households that reduced vegetable and livestock production and paid more to access water would have faced more water stress by about 39, 57, and 73%, respectively, if they had not. Again, those who did not reduce vegetable or

Table 5 | Endogenous switching regression models for impact adaptation strategies on household level water stress.

		Reducing Vegetable		Reducing livestock		Pay more		Preservation		Increase in time		Reservoir	
Row No.	**Variables**	**Adoption**	**Non-adoption**	**Adoption**	**Non-adoption**	**Adoption**	**Non-adoption**	**Adoption**	**Non-adoption**	**Adoption**	**Non-adoption**	**Adoption**	**Non-adoption**
1	Age (Base ≤30 years)												
2	31 to ≤40 years	−0.015 (0.029)	−0.010 (0.027)	−0.019 (0.033)	−0.079** (0.038)	0.018 (0.030)	−0.021 (0.034)	−0.043 (0.032)	0.003 (0.028)	−0.029 (0.027)	−0.013 (0.033)	−0.017 (0.030)	−0.011 (0.026)
3	41 to ≤50 years	−0.031 (0.032)	0.008 (0.030)	−0.007 (0.037)	−0.026 (0.041)	0.057* (0.032)	−0.010 (0.037)	−0.002 (0.035)	−0.000 (0.029)	0.002 (0.028)	0.029 (0.036)	0.003 (0.033)	0.021 (0.030)
4	Above 50 years	−0.034 (0.034)	0.098*** (0.033)	−0.013 (0.037)	0.017 (0.041)	0.010 (0.034)	0.057 (0.040)	−0.023 (0.036)	0.053* (0.032)	0.008 (0.030)	0.060 (0.038)	0.014 (0.034)	0.077** (0.034)
5	Gender (Male=1; otherwise=0)	0.052 (0.045)	−0.014 (0.037)	0.090 (0.061)	−0.013 (0.045)	−0.054 (0.044)	−0.005 (0.044)	−0.017 (0.045)	0.006 (0.036)	−0.013 (0.036)	−0.021 (0.044)	−0.012 (0.041)	0.026 (0.039)
6	Religion (Islam=1; otherwise=0	−0.023 (0.025)	0.042 (0.026)	−0.003 (0.028)	0.030 (0.031)	−0.027 (0.024)	0.039 (0.030)	−0.033 (0.027)	0.013 (0.022)	0.009 (0.021)	−0.058* (0.031)	−0.020 (0.024)	0.006 (0.023)
7	Literacy level (Base: Illiterate)												
8	Illiterate to below primary	−0.061* (0.031)	0.088*** (0.033)	−0.015 (0.035)	0.017 (0.041)	0.028 (0.032)	0.066* (0.034)	0.012 (0.036)	0.068** (0.030)	0.025 (0.029)	0.030 (0.035)	0.005 (0.031)	0.099*** (0.030)
9	Primary to below secondary	−0.007 (0.024)	0.075** (0.029)	0.030 (0.028)	0.016 (0.033)	0.052** (0.026)	0.081*** (0.028)	0.038 (0.028)	0.062*** (0.024)	0.048** (0.022)	0.051* (0.028)	0.041 (0.026)	0.082*** (0.024)
10	Secondary or above	−0.035 (0.032)	0.110*** (0.036)	0.005 (0.039)	0.014 (0.042)	0.063* (0.033)	0.086** (0.036)	0.029 (0.036)	0.072** (0.030)	0.039 (0.029)	0.046 (0.032)	0.033 (0.032)	0.080*** (0.030)
11	Employment status (Base: Unemployed)												
12	Farming	−0.039 (0.045)	0.064 (0.039)	−0.022 (0.057)	−0.003 (0.047)	0.085* (0.047)	0.028 (0.043)	0.062 (0.049)	0.009 (0.037)	0.001 (0.039)	0.054 (0.046)	0.024 (0.046)	0.001 (0.038)
13	Day laborer	−0.053 (0.046)	0.032 (0.037)	−0.063 (0.055)	−0.031 (0.045)	0.031 (0.044)	0.053 (0.041)	0.012 (0.048)	0.006 (0.034)	−0.010 (0.038)	0.030 (0.043)	0.008 (0.044)	−0.020 (0.036)
14	Business/ service	−0.039 (0.058)	0.004 (0.044)	−0.026 (0.069)	−0.077 (0.055)	0.080 (0.057)	0.010 (0.053)	0.031 (0.061)	0.019 (0.040)	−0.017 (0.050)	0.020 (0.054)	−0.019 (0.059)	−0.010 (0.043)

(*Continued.*)

Table 5 | Continued

		Reducing Vegetable		Reducing livestock		Pay more		Preservation		Increase in time		Reservoir	
Row No.	**Variables**	**Adoption**	**Non-adoption**	**Adoption**	**Non-adoption**	**Adoption**	**Non-adoption**	**Adoption**	**Non-adoption**	**Adoption**	**Non-adoption**	**Adoption**	**Non-adoption**
15	Standardized Male Female ratio	−0.21*** (0.051)	−0.18*** (0.050)	−0.28*** (0.063)	−0.24*** (0.066)	−0.26*** (0.054)	−0.17*** (0.057)	−0.3*** (0.064)	−0.105** (0.046)	−0.23*** (0.049)	−0.17*** (0.062)	−0.29*** (0.053)	−0.15*** (0.047)
16	Standardized dependency ration	−0.180** (0.072)	−0.18*** (0.066)	−0.154** (0.077)	−0.118 (0.079)	−0.163** (0.069)	−0.194** (0.078)	−0.171** (0.080)	−0.139** (0.058)	−0.136** (0.063)	0.050 (0.074)	−0.160** (0.071)	−0.138** (0.061)
17	Household size	−0.03*** (0.006)	−0.005 (0.006)	−0.02*** (0.007)	−0.006 (0.007)	−0.02*** (0.007)	−0.02*** (0.006)	−0.02*** (0.007)	−0.005 (0.005)	−0.011** (0.006)	−0.02*** (0.006)	−0.016** (0.007)	−0.010* (0.006)
18	Distance from drinking water Sources	−0.000 (0.001)	−0.001 (0.002)	−0.002 (0.001)	−0.001 (0.002)	0.002 (0.001)	0.015*** (0.003)	0.001 (0.001)	−0.003* (0.002)	−0.001 (0.001)	0.003 (0.002)	−0.000 (0.001)	−0.002 (0.002)
19	Distance from non-drinking water Sources	0.011** (0.005)	−0.012 (0.007)	0.006 (0.006)	−0.009 (0.006)	0.010** (0.005)	−0.03*** (0.008)	0.005 (0.005)	−0.005 (0.008)	0.002 (0.004)	−0.001 (0.009)	0.006 (0.005)	−0.010 (0.009)
20	Access to Tube-well	−0.051** (0.025)	−0.038* (0.020)	−0.053* (0.030)	−0.08*** (0.026)	−0.14*** (0.023)	−0.09*** (0.027)	−0.09*** (0.025)	−0.005 (0.022)	−0.07*** (0.020)	−0.07*** (0.023)	−0.10*** (0.026)	−0.039* (0.021)
21	Support from GOs and NGOs	0.028 (0.030)	−0.039 (0.026)	−0.020 (0.035)	−0.013 (0.028)	0.072** (0.028)	0.022 (0.028)	−0.009 (0.035)	0.005 (0.021)	0.012 (0.026)	−0.014 (0.027)	0.008 (0.032)	0.006 (0.026)
22	Migration (Yes=1; otherwise=0)	0.035 (0.034)	0.121*** (0.046)	0.109*** (0.033)	0.159** (0.064)	0.134*** (0.032)	0.082 (0.056)	0.070* (0.038)	0.128** (0.054)	0.070** (0.030)	0.172*** (0.055)	0.092*** (0.033)	0.084 (0.068)
23	Homestead damage due to flood	0.034 (0.028)	0.057*** (0.022)	0.014 (0.029)	0.112*** (0.030)	−0.019 (0.028)	0.113*** (0.027)	−0.061** (0.030)	0.068*** (0.021)	0.048* (0.025)	−0.019 (0.031)	0.097*** (0.028)	0.019 (0.026)
24	Homestead damage due to riverbank erosion	0.054* (0.028)	0.054** (0.026)	0.077** (0.031)	0.004 (0.033)	0.043 (0.027)	0.016 (0.030)	0.087*** (0.032)	0.028 (0.023)	0.030 (0.025)	0.067** (0.034)	0.019 (0.029)	0.058** (0.024)
25	Income (in ‘000 BDT)	−0.002 (0.002)	−0.001 (0.001)	−0.01*** (0.003)	0.000 (0.002)	−0.002 (0.002)	−0.001 (0.002)	−0.005** (0.003)	0.000 (0.001)	0.000 (0.001)	−0.002 (0.002)	−0.003 (0.003)	−0.001 (0.001)

(*Continued.*)

Table 5 | Continued

Row No.	Variables	Reducing Vegetable Adoption	Reducing Vegetable Non-adoption	Reducing livestock Adoption	Reducing livestock Non-adoption	Pay more Adoption	Pay more Non-adoption	Preservation Adoption	Preservation Non-adoption	Increase in time Adoption	Increase in time Non-adoption	Reservoir Adoption	Reservoir Non-adoption
26	Union (Base: Dakshin Bedkashi)												
27	Gabura	0.022	0.012	0.035	0.049	0.030	−0.010	0.044	−0.005	−0.007	0.053	0.022	0.037
		(0.027)	(0.037)	(0.030)	(0.036)	(0.029)	(0.035)	(0.037)	(0.032)	(0.027)	(0.034)	(0.030)	(0.036)
28	Laudob	0.095*	0.306**	0.050	0.264***	0.002	0.030	0.210***	−0.137	0.116**	−0.079	0.152***	−0.25***
		(0.054)	(0.121)	(0.060)	(0.084)	(0.067)	(0.060)	(0.065)	(0.123)	(0.050)	(0.067)	(0.056)	(0.062)
29	Protapnagar	−0.082*	−0.036	−0.056	−0.041	0.163***	0.058	−0.026	0.007	−0.056	0.073*	−0.008	0.017
		(0.045)	(0.036)	(0.096)	(0.042)	(0.047)	(0.043)	(0.061)	(0.029)	(0.048)	(0.040)	(0.057)	(0.035)
30	Sreeula	0.114**	0.088**	−0.097*	0.133***	0.256***	0.077*	0.267***	0.124***	0.194***	0.279***	0.079	0.166***
		(0.045)	(0.038)	(0.056)	(0.048)	(0.043)	(0.046)	(0.051)	(0.041)	(0.038)	(0.047)	(0.048)	(0.035)
31	Tildanga	0.035	0.101**	0.198***	0.104**	0.243***	0.094**	0.382***	0.098**	0.210***	0.183***	0.271***	0.113**
		(0.060)	(0.046)	(0.055)	(0.050)	(0.062)	(0.047)	(0.056)	(0.043)	(0.047)	(0.053)	(0.047)	(0.046)
32	Uttar Bedkashi	−0.058**	−0.009	−0.035	0.078	−0.034	0.014	−0.022	−0.005	−0.047	−0.044	−0.021	0.013
		(0.029)	(0.036)	(0.032)	(0.047)	(0.031)	(0.041)	(0.040)	(0.034)	(0.029)	(0.046)	(0.032)	(0.041)
33	Constant	0.667***	0.630***	0.639***	0.801***	0.532***	0.734***	0.634***	0.520***	0.587***	0.775***	0.604***	0.597***
		(0.046)	(0.066)	(0.059)	(0.074)	(0.054)	(0.060)	(0.064)	(0.060)	(0.050)	(0.028)	(0.050)	(0.057)
34	Observations	500	500	500	500	500	500	500	500	500	500	500	500
35	ρ_A	16.587 (112.761)		14.927 (52.709)		1.460*** (0.259)		16.311 (95.343)		1.078*** (0.187)		16.945 (134.627)	
36	ρ_N	0.846*** (0.252)		15.648 (74.541)		16.553 (107.714)		0.355 (0.294)		17.067 (141.018)		1.000** (0.458)	

Standard errors in parentheses.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

We discarded two observations due to missing values from our total samples.

Table 6 | Treatment effect of adaptation strategies on household level water stress.

Adaptation type	Sub-samples	Decision stage		Treatment effect	Treatment effect relative to control mean (%)	
1	2	3	4	5	6	7
		Adoption	Non-adoption		Observed	Counter-factual
Reducing vegetable production	Households adopted	0.49	0.72	TT=−0.23***	−15.52	−38.98
	Households did not adopt	0.25	0.58	TU=−0.34***		−57.63
Reducing livestock	Households adopted	0.50	0.82	TT=−0.32***	−10.71	−57.14
	Households did not adopt	0.24	0.56	TU=−0.32***		−57.14
Pay more	Households adopted	0.51	0.92	TT=−0.41***	−8.93	−73.21
	Households did not adopt	0.31	0.56	TU=−0.25***		−44.64
Preservation	Households adopted	0.54	0.57	TT=−0.03***	1.89	−5.66
	Households did not adopt	0.19	0.53	TU=−0.34***		−64.15
Increase in time	Households adopted	0.53	0.80	TT=−0.27***	0.00	−50.00
	Households did not adopt	0.37	0.53	TU=−0.16***		−29.63
Use of reservoir	Households adopted	0.54	0.65	TT=−0.11***	1.89	−20.75
	Households did not adopt	0.25	0.53	TU=−0.28 ***		−52.83

*** $p<0.01$.

TT: Treatment on the treated; TU: Treatment on the untreated.

livestock production or pay more to access water would have faced less water stress by about 58, 57, and 45%, respectively, as revealed from treatment on the untreated analysis (TU) shown in Table 6.

Results from the observed analysis further suggest that households that preserved water and used reservoirs for collecting water experienced about 2% more water stress in each case than those who did not. However, counterfactual analyses show the opposite scenario. Treatment on the treated (TT) results denote that respondent households who preserved water and used reservoirs for collecting water would have faced less water stress by about 6 and 21%, respectively, if they had not (see Table 6). On the other hand, TT results show that households that did not preserve water and use reservoirs for collecting water would have faced less water stress by about 64 and 53%, respectively if they had. In addition, findings suggest that households that increased the time for water collection would have experienced about 50% more water stress if they had not, and the non-adopters would have experienced 30% less water stress if they had adopted, even though there is barely any difference in water stress between observed adopter and non-adopter households for the 'increase time for water collection' adaptation strategy.

5. CONCLUSIONS

Problems related to water scarcity are acute and becoming a significant concern to countries vulnerable to climate change impacts, especially in the global south. Being a part of the global south and having a vast coastal zone, Bangladesh also encounters water stress with its increased population growth rate. People in coastal areas in Bangladesh are exposed to severe water crises because of inadequate access to fresh and safe water, which is intensifying due to different degrees of salinity intrusion and arsenic contamination and frequent extreme climatic events. This study has attempted to contribute to the existing literature by exploring the determinants and impacts of adaptation strategies for coastal households at risk from water stress, addressing the behaviors of adopters and non-adopters. To the very best knowledge of the authors, this is the first study on south-western coastal Bangladesh that presents empirical results from counter-factual analysis of adaptation strategies to withstand water stress.

This study identified six adaptation strategies that the respondent households practiced in the study locations to withstand water stress. Empirical analyses, made by applying an endogenous switching regression model, suggest that both observed and unobserved factors influence the decision to adopt different adaptation strategies. Migration due to water stress and support from government organizations (GOs) and non-government organizations (NGOs) are the main determinants in adopting the adaptation strategies for reducing water stress at the household level. Also, socioeconomic characteristics such as age, gender, education, occupation, income, access to tube wells, and distance from drinking water sources play a significant role in adopting adaptation strategies. Again, perception of changes in frequency, intensity, and rainfall duration also significantly influences various adaptation strategies. Adoption of adaptation strategies appears to significantly reduce household-level water stress. Our findings indicate that all adaptation strategies – reducing vegetable and livestock production, paying more to access water, increasing time for water collection, preserving water, and using the reservoir for collecting water – have a significant impact on households' water stress. Besides, on average, households that did not adopt adaptation strategies would have faced less water stress if they had adopted. Therefore, factors that promote adaptation strategies would indirectly reduce households' degree of water stress.

These findings could be crucial in formulating policies for effective adaptation strategies to address the potential effects of water stress. Based on these empirical findings, two key policy suggestions can be drawn. First, accelerating easy access to financial support from government and non-government organizations could encourage the implementation of adaptation measures to reduce water stress. Second, dissemination of climatic information (i.e., frequency, intensity, and duration of rainfall) would raise at-risk households' awareness of different adaptation strategies, which eventually would reduce these households' water stress. In this context, promoting different adaptation measures among households could be an important strategy for reducing water stress significantly. Public policies for adopting effective adaptation measures can play a crucial role at the household level. Additionally, further research could be carried out to identify the most successful adaptation strategies.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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