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Perception of coastal citizens on the prospect of community-based rainwater harvesting system for sustainable water resource management

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ABSTRACT

Predominant water scarcity and environmental degradation in Bangladesh's coastal communities arise due to extreme meteorological conditions, unrestrained water usage, and extensive saline intrusion into both surface and groundwater. This study leverages both quantitative data from a household survey and qualitative data from a Participatory Rural Appraisal to explore the perspectives of 150 official experts and 240 coastal public respondents regarding the implementation of a "Community-Based Rainwater Harvesting System" (CBRWHS) as a sustainable water supply technology in six major coastal districts of Bangladesh. Though CBRWHS surpasses the benefits of an individual harvesting system (IHS) due to its collective approach, high storage capacity, social cohesiveness, environmental benefits, and potential for scalability, findings suggest that the experts identify financial insolvency, lack of technical skills, and insufficient education as principal barriers against adopting CBRWHS. They propose that providing technical instructions, education, and establishing a CBRWHS pilot could serve as effective incentives. While expressing a sufficient understanding of IHS, respondents are willing to adopt CBRWHS only if financial support is provided. Given the residents' experience with IHS, they are cognizant of the financial and technical challenges intrinsic to such systems. CBRWHS, unlike IHS, operates as a shared system with collective property rights and regulations. Majority of respondents perceive CBRWHS as a potential significant mitigation tool against the water shortage situation since the challenges associated with harvesting, maintaining, and using rainwater could be addressed collectively by the user community. Similar to the official experts, public respondents identify a lack of technical expertise, financial constraints, and regulations as the most significant obstacles to IHS adoption. The findings of this study hold substantial implications not only for the local region but also for similar coastal regions worldwide, suggesting a crucial need for the prioritization of community-based solutions to water scarcity within the wider global discourse on sustainable water management.

Abbreviations: PRA, Participatory Rural Appraisal; IHB, Individual Household Based; RW, Rainwater; RWHS, Rainwater Harvesting System; CAS, Coastal Adaptation Strategies; WARPO, Water Resource Planning Organization IWM-Institute of Water Modeling; CBRWHS, Community Based Rainwater Harvesting System; PSF, Pond Sand Filter; RO, Reverse Osmosis; LGED, Local Government Engineering Department; DPHE, Department of Public Health Engineering; BWDB, Bangladesh Water Development Board; CEGIS, Center for Environment and Geographic Information Services; DoE, Department of Environment.

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1. Introduction

Water is undeniably one of the most essential substances for the survival and wellbeing of all living organisms. The significance of water is evident in every aspect of life, from the maintenance of human health to the maintenance of ecosystems (Almulhim and Abubakar, 2023). The right to access clean and safe drinking water is a fundamental human right, yet millions of individuals around the world lack access to this basic necessity, leading to widespread health problems and preventable deaths (WHO, 2019). Globally, over 2.2 billion people lack access to safe drinking water, which is equivalent to around 29% of the global population. One in three people around the world lacks access to safe drinking water and approximately 4.2 billion people living in areas where severe water scarcity is experienced at least once a year (WHO, 2019). Rapid population growth, water pollution, over-extraction, habitant destruction, land cover change, and climate change have all contributed to declining freshwater sources, further exacerbating the problem in many regions (Tapsuwan et al., 2018; Almulhim et al., 2021; Almulhim and Cobbinah, 2023a,b). Recognizing water's utmost significance, it is crucial for individuals, communities, and governments to prioritize responsible water management, proper use of alternative sources, conservation efforts, and equitable access to ensure the preservation of this precious resource for current and future generations (Burns et al., 2015; Ghosh and Ahmed, 2022; Almulhim and Al-Saidi, 2023).

Declining freshwater sources around the world are a pressing issue with significant socioeconomic and environmental implications. In coastal areas, the freshwater crisis is more pronounced (Sultana et al., 2015). Coastal areas often have limited access to freshwater sources such as rivers and lakes. They rely heavily on groundwater for freshwater. However, over-extraction of groundwater in coastal regions may lead to saltwater intrusion, making the freshwater scarcity problem in coastal communities worse. Water is a cornerstone of agricultural production, supporting food security and livelihoods for billions of people. Lack of water leads to decreased crop yields and an increase in food shortages (Abdullah and Rahman, 2015; Chowdhury, 2023). Sea-level rise due to glaciers melting and the polar ice caps melting, causing saltwater to intrude into coastal aquifers and contaminating freshwater sources. Additionally, climate change also affects rainfall patterns, with some coastal regions experiencing irregular precipitation or prolonged dry seasons, resulting in a greater shortage of freshwater. In such situations, harnessing rainwater can be an eminent source of freshwater, which can significantly alleviate the freshwater crisis (Islam et al., 2019; Dao et al., 2021).

Rainwater is a vital freshwater resource, especially in regions grappling with severe water shortages. The practice of rainwater harvesting involves capturing, storing, and managing the rainwater collected from roofs, land surfaces, and other catchment areas for later use. This collected rainwater can serve various purposes including domestic use, irrigation, livestock, and groundwater recharge, thereby playing a critical role in water security (Akhter and Ahmed, 2015). Community-based rainwater harvesting system (CBRWHS) refers to rainwater harvesting initiatives implemented and managed at the community level. Unlike individual rainwater harvesting systems (RWHS) typically adopted by single households, the CBRWHS operates on a larger, communal scale. It involves the active participation of community members in every phase of the rainwater harvesting initiative, from planning and implementation to maintenance. The term "community-based" specifically refers to the underlying principle of collective ownership and shared responsibility. In CBRWHS, the system isn't confined to an individual property but is installed in a shared space within the community. The upkeep of the system, decision-making about the usage of collected water, and troubleshooting any issues are undertaken collectively, fostering cooperation, and shared benefit. Experience has demonstrated that rainwater harvesting projects are often more sustainable and effective when adopting community-based approaches. These systems consider local knowledge, promote social cohesion, and advocate collective action, thereby contributing to increased social resilience and environmental sustainability (Kim et al., 2016). While the technical and engineering aspects of RWHS have been extensively examined in previous studies (Karim, 2010; Dao et al., 2021; Ravenscroft et al., 2014), there remains a gap in understanding the socioeconomic dynamics influencing the adoption, use, and maintenance of RWHS at the community level.

Bangladesh is a riverine country with a very complex network of around 230 rivers flowing currently. Despite being a riverine country, it suffers from safe water crises. This safe water crisis is not only dominant in Bangladesh; it is also becoming a global crisis. Studies depict that 70% of the earth's surface is water, but still, it is extremely challenging for many countries to ensure freshwater availability (Pala, Pathivada et al. 2021). In Bangladesh, approximately 35% of the total population has direct or indirect access to safe water for drinking (UNICEF,2018). Among the global coastal population, the majority of the percentage lives in Asia and studies showed the approximate percentage residing in Asian countries are more than 75% (ADB, 2013). Bangladesh's coastline extends 710 km of the Bay of Bengal and unfortunately, when it comes to the coastal zones of Bangladesh, the crisis of freshwater problem is most acute (MoWR, 2005; Ravenscroft et al., 2014; Islam et al., 2019). Limited surface water resources, intrusion of saline water into freshwater, urbanization coupled by population growth, natural disasters, extreme climate change events have been impacting the water sources in the coastal areas of Bangladesh. All these are creating severe shortages of freshwater in the coastal areas and impacting the livelihoods and wellbeing of local communities (Abdullah and Rahman, 2015). There is an acute shortage of shallow water aquifers and fresh surface water, and the situation is getting exacerbated due to salinity intrusion by people in the coastal part of Bangladesh (Islam et al., 2011). Moreover, the quality of drinking water in coastal areas is of major concern due to the presence of various contaminants and the vulnerability of water sources to contamination. Being one of the most prominent climate-ravaged coastal zones in the world, freshwater supply has become a crucial issue (Mukherjee and Hyde, 2013). In such unfavorable and drastic situations, rainwater harvesting can play a significant role.

A significant number of households in the coastal areas of Bangladesh have adopted individual household based (IHB) freshwater collection methods. However, according to Ravenscroft et al. (2014), approximately 24% of these systems are non-functional due to inadequate maintenance. Coastal adaptation strategies (CAS) such as reverse osmosis (RO), pond sand filters (PSF), tube wells, and pond water conservation pose challenges for coastal livelihoods, requiring technical knowledge and financial resources for maintenance (Neibaur and Anderson, 2016). In light of these difficulties, the CBRWH system proves advantageous compared to the IHB RHS, given its collective approach to water management and tailored response to the specific challenges faced in coastal areas (Kim et al., 2016). CBRWHS enables the pooling of resources and expertise to construct more sophisticated and larger rainwater harvesting structures in low-income settings. This increases water storage capacity, improves distribution systems, and improves infrastructure maintenance, ultimately benefiting more households (Hoffman et al., 2021). Moreover, CBRWHS surpasses the benefits of the IHB system because of its scalability and potential for long-term impacts, which promote a more sustainable solution (Dallman et al., 2016). Additionally, CBRWHS is comparatively more coefficient than IHB system (Triyono et al., 2019) and have more environmental benefits (Raya and Gupta, 2020). While a limited number of studies have assessed the rainwater RHW system in coastal regions around the world (Gosh and Ahmed, 2022; Raenscroft et al., 2014; Islam et al., 2019; Karim et al., 2005), all of them are focused on the IHB RHS. Moreover, no prior studies have specifically explored people's willingness to pay (WTP) for the development and maintenance of the CBRWHS.

The present research aims to address the crucial global issue of water scarcity, focusing specifically on the coastal areas of Bangladesh, where the problem is most acute. Despite the wealth of studies examining technical and engineering aspects of RHS, there has been a distinct lack of investigation into socioeconomic factors that influence the adoption, utilization, and maintenance of RHS on a community level. To fill this gap, the research will delve into the suitability of the CBRWHS in Bangladesh's coastal regions and assess the community's WTP for the development and maintenance of this system. This investigation is both *novel and vital*; no prior research has explicitly explored WTP for CBRWHS development and maintenance. This research's *intellectual merit* stems from its comprehensive approach that amalgamates top-down and bottom-up methodologies to pinpoint factors affecting WTP for CBRWHS. This strategy ensures a robust understanding of the local dynamics, incorporating community-level perspectives with overarching structural elements, promoting a more nuanced understanding of the feasibility and viability of the CBRWHS in Bangladesh's coastal regions. It also provides a new lens through which to examine an increasingly prevalent global issue - the looming water crisis. The *broader impacts* of this research have the potential to reach well beyond the national borders of Bangladesh. With the majority of the global coastal population residing in Asia, the findings from this study may apply to similar coastal contexts across the continent. More broadly, as climate change continues to exacerbate water scarcity issues worldwide, insights from this research could contribute to the development and implementation of community-based strategies in other vulnerable regions.

By augmenting existing knowledge about community-based water management strategies and presenting innovative, locally driven solutions, this research could prompt policy shifts and foster more sustainable, equitable, and adaptive approaches to water management globally. These findings will be invaluable in directing the design of efficient community engagement strategies, capacity-building initiatives, and infrastructure development plans tailored to the unique needs of local communities. In the end, the ultimate objective of this research is to inform effective, sustainable strategies that can contribute significantly to global efforts to secure safe water for all. By filling these knowledge gaps, this study contributes to the expansion of current knowledge and provides practical insights for sustainable water management, policy development, and community-level interventions in climate-vulnerable regions. The findings of this study will be valuable in guiding the design of effective community engagement strategies, capacity-building initiatives, infrastructure development plans and accomplishment of SDG 6 by ensuring safe and sustainable water by 2030 that are tailored to the specific needs of local communities.

2. Materials and methods

2.1. Study area and study design

Situated in the southern portion of the country, the coastal areas of Bangladesh possess a distinct significance due to their unique geographical attributes, climatic conditions, population demographics, and contributions to the national economy. Out of the 64 districts in Bangladesh, 19 are coastal, boasting approximately 710 km of coastline along the Bay of Bengal (BBS, 2011). Major cities such as Chittagong, Cox's Bazar, and Khulna, which attract substantial populations, are nestled along this coastline. With around 40 million inhabitants, these coastal areas house about 34% of Bangladesh's population. This study selected six major coastal cities - Khulna, Barisal, Feni, Noakhali, Bagerhat, and Patuakhali - as study units (Fig. 1 and 2). The high population density in these regions presents an array of social, economic, and environmental hurdles. A substantial portion of the coastal communities' income is earned from fishing, agriculture, and other coastal livelihood activities.

The climate of the coastal region is heavily influenced by the Bay of Bengal's proximity and the presence of the Sundarbans, the world's largest mangrove forest. The area experiences a humid climate with three distinct seasons: pre-monsoon (March to June), monsoon (July to October), and post-monsoon (November to February). Annual precipitation ranges from 150 to 200 cm, with approximately 70% falling during the monsoon period (Kabir et al., 2016). Indeed, about 75% of precipitation in these locations occurs between June and September, during the rainy season (Sarker et al., 2018). The tropical monsoon climate during the monsoon season brings with it high humidity, substantial rainfall, and intense cyclones. Natural calamities such as cyclones, storm surges, and coastal erosion pose significant threats. Climate change-induced phenomena, including sea-level rise, salinity intrusion, and erosion, present severe risks to communities, livelihoods, and infrastructure in these coastal areas. Consequently, these disasters exacerbate the problem of freshwater scarcity in the region (Abdullah and Rahman, 2015). The residents of these areas often face water scarcity-related issues, with a majority of households utilizing rainwater harvesting (RWH) as a potential freshwater source (Islam et al., 2019).

The region suffer from a dearth of both surface and groundwater, significantly impacting the lives and livelihoods of residents. The World Bank estimates that approximately 75% of the coastal population primarily relies on groundwater for drinking. However, this water is often of poor quality due to high salinity, arsenic, and other contaminants. Additionally, the coastal region confronts a surface water shortage exacerbated by climate change impacts such as rising sea levels, increased extreme weather events, and diminished river flows. Increased water scarcity in this region leads to a greater reliance on bottled water, an expensive commodity not always accessible to many people (Habib et al., 2021). Notably, salinity intrusion has emerged as a critical concern, exerting a severe impact on Bangladesh's coastal regions. Over time, the combined effects of climate change will exacerbate the problem of salinity intrusion and further contribute to the inundation of low-lying lands (World Bank, 2000). Consequently, the coastal areas of Bangladesh will progressively lose the capacity to provide vital "environmental services" (Shahid et al., 2013). The typical problems associated with water salinity in coastal areas are illustrated in Fig. 3.

2.2. Feasibility of rainwater harvesting

RWH has emerged as a potential solution to address freshwater-related problems in the safe water-scarce coastal zones of Bangladesh, as the country receives nearly 2600 mm of rainfall each year (Karim et al., 2015). With the increasing water demand in coastal areas, the development of RWHS has gained much attention. Since coastal areas of Bangladesh receives ample amount of rainfall throughout the year so harvesting of rainwater is a potential source of freshwater. So, studies depict that RWH can be an excellent alternative water supply option in the coastal part of Bangladesh as these parts receive comparatively more rainfall throughout the year (Bashar et al., 2018). Fig. 4 depicts the rainfall patterns in the selected coastal regions of Bangladesh for this study.

2.3. Data collection

This study prepared two sets of questionnaires for data collection: one for official experts and another for community members. To ensure a comprehensive approach, both qualitative methods, such as focus group discussions (FGDs) conducted using Participatory Rural Appraisal (PRA) tools, and quantitative methods, including a household survey, were employed. This mixed-method strategy allowed for collecting primary data from the community and insights from official experts involved in water governance. A total of 240 community members and 150 professionals from water governance institutions and agencies were surveyed between January and May of 2022. Verbal interviews and real-time conversations were conducted in person as part of the public survey, which spanned six major coastal cities in Bangladesh (Khulna, Barisal, Feni, Noakhali, Bagerhat, and Patuakhali), aiming to provide a comprehensive understanding of the coastal zones in the country. Prior

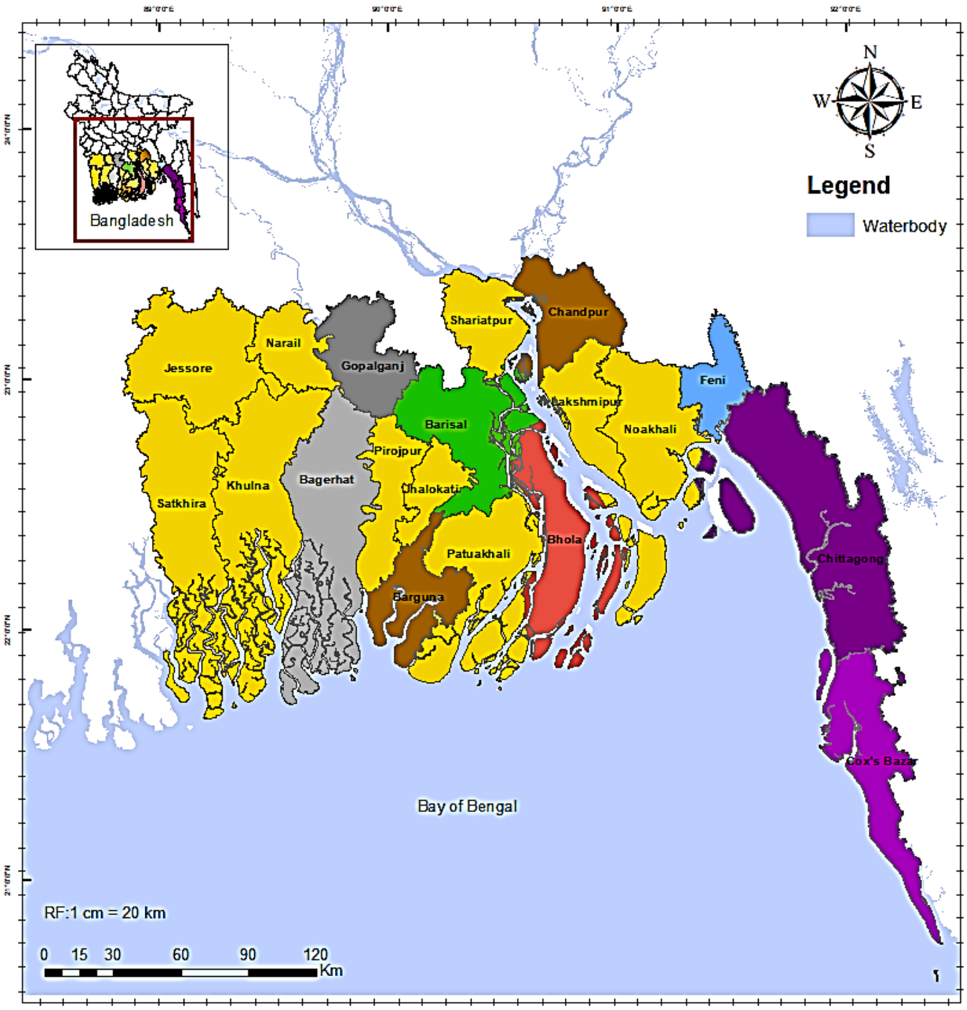

Fig. 1. Coastal districts of Bangladesh.

to the field visits, enumerators and surveyors underwent training, and the questionnaire questions were piloted and tested.

FGDs were conducted in each city to enhance the analysis to create participatory maps and conduct a SWOT analysis. In some cases, separate interviews were conducted with male and female participants to gain insights into gendered experiences, although the number of female participants was relatively low. General participants were selected randomly, and in each district, six to eight locations were chosen randomly for interviews with at least five volunteer respondents at each location. Field interviews with participants are illustrated in Fig. 5.

The expert opinions were obtained from the experts of the Local Government Engineering Department (LGED), Department of Public Health Engineering (DPHE), Water Resource Planning Organization (WARPO), Bangladesh Water Development Board (BWDB), Bangladesh Haor & Wetland Development Board, Institute of Water Modeling (IWM), Water and Sewerage Authorities, Center for Environment and Geographic Information Services (CEGIS), Department of Environment (DoE), Joint River Commission, Flood Forecasting Warming Center and National River Protection Commission. The collected data were then processed, evaluated, and interpreted in alignment with the study's objectives. To ensure the validity and triangulation of the field visit results (Chambers, 2002), a regional workshop was conducted on June 17, 2022, using the online Zoom platform. The workshop was conducted in local language. All of the ethical issues e.g., proper informed consent forms from the participants, anonymous recording of the data, etc. were maintained during data collection.

2.4. Data analysis

Following a rigorous data collection process, this study embarked on a comprehensive data analysis phase, meticulously addressing the salient issues of water scarcity and environmental degradation prevalent in the coastal communities of Bangladesh. The analysis was grounded in a detailed examination of both quantitative and qualitative data sets, thoughtfully integrated to provide a thorough and nuanced understanding of the community's perspectives on CBRWHS.

Primary quantitative data derived from a household survey was analyzed in SPSS, for simple descriptive statistics to more complex inferential analyses, helping decipher the complex relationships in our data set. The univariate analysis were conducted for an initial understanding of each variable in isolation, and bivariate analysis to reveal possible correlations and associations between variables (Levin et al., 2017). A qualitative analysis of data derived from the PRA was performed in conjunction with the statistical examination. This analysis focused on interpreting and understanding the official expert's and coastal public respondents' underlying perspectives, motivations, and experiences. It illuminated several critical insights, such as the public's acknowledgement of the challenges intrinsic to CBRWHS and the experts' suggestions for overcoming these barriers. A key aspect of the data analysis was the comparative evaluation of expert and public perspectives.

We implemented a robust data analysis protocol to delve into the complex environmental factors contributing to the water scarcity issues in Bangladesh's coastal communities. Central to this process was the use

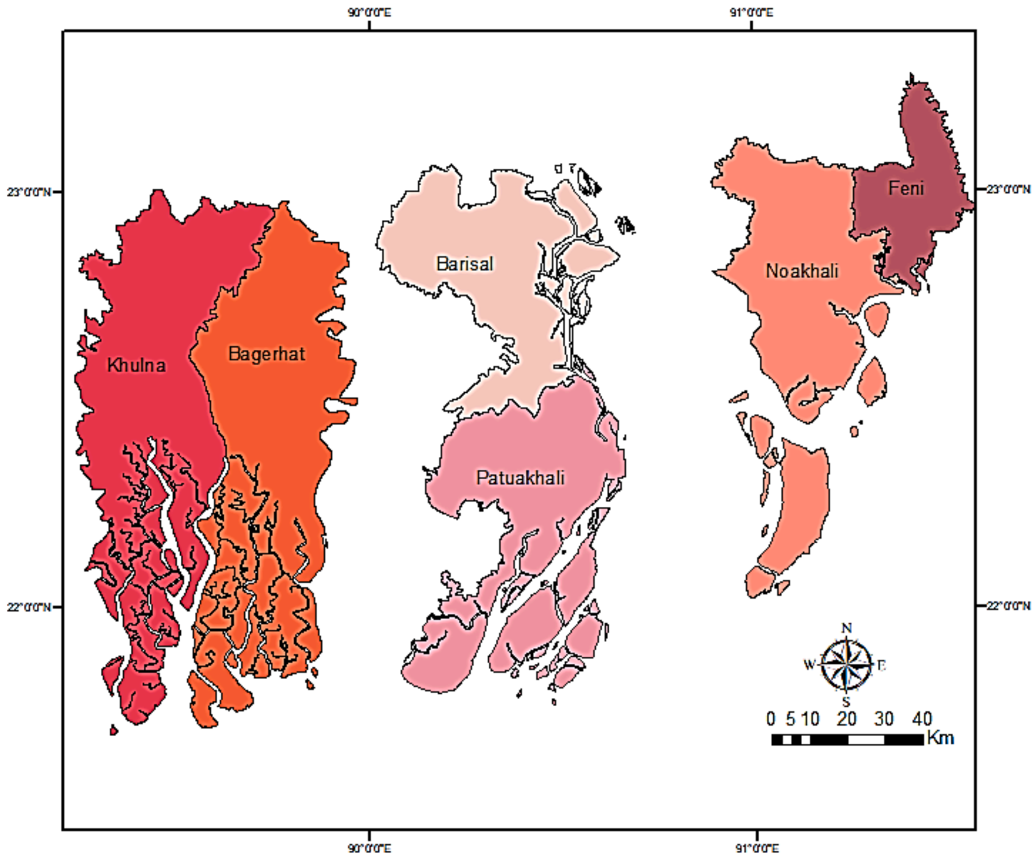

Fig. 2. Location of Study Area.

of monthly precipitation data collected from 18 distinct stations spread across the coastal areas of Bangladesh. This information was obtained courtesy of the Bangladesh Meteorological Department. Once acquired, the precipitation data were subjected to rigorous analysis via ArcGIS 10.8. In this case, the Kriging interpolation method (Krivoruchko, 2012) was employed to map rainfall. This advanced interpolation technique was instrumental in creating high-resolution spatial rainfall maps, providing a geographical dimension to the existing data and revealing correlations with meteorological conditions, one of the root causes of water scarcity in these areas (Oliver and Webster, 2014).

Collectively, the application of these methods and tools allowed us to transform our raw data into a rich tapestry of insights, underpinning the conclusions drawn in our study. By combining GIS with rigorous statistical analysis, we ensured a comprehensive, multi-dimensional exploration of the issues at hand.

2.5. Willingness to pay analysis

Willingness to Pay (WTP) analysis is an economic technique used to quantify individuals' perceived value on specific goods or services. In essence, it computes the maximum amount a person would be willing to part with to attain a benefit or circumvent a negative consequence. The crux of this research lies in understanding and quantifying the local population's and experts' readiness to invest in implementing a CBRWHS as a sustainable water supply solution in the coastal regions of Bangladesh.

This study used two approaches to ascertain WTP: the Contingent Valuation Method (CVM) and the Revealed Preference Method (RPM). CVM is a stated preference method that uses direct inquiry to estimate the monetary value individuals place on non-market goods or services. This approach is particularly germane to WTP analyses for its flexibility and its capacity to value commodities without a market or where market prices do not accurately reflect their worth. RPM, on the other hand, deduces WTP from the observed behavior of individuals in real markets. While this study prioritized the use of CVM, due to the absence of a functioning market for CBRWHS, RPM methods informed some aspects of the valuation, particularly those related to existing, comparable water technologies.

Regarding statistical techniques, multiple linear regression analysis was utilized to compute the WTP, with household income, education level, age, and household size as independent variables. These variables were carefully chosen based on their relevance to WTP as inferred from past studies (Fattah et al., 2022) and to capture the heterogeneity within the population. The responses were measured on an ordinal scale, utilizing a five-point Likert scale, where 1 signifies 'not at all willing to pay, ' and 5 indicates 'extremely willing to pay.' This method ensures that the analysis captured varying degrees of WTP, allowing a nuanced understanding of the data collected.

We considered both top-down and bottom-up approaches to estimate the aggregate WTP. Top-down methods utilize existing market data to provide aggregate insights, whereas bottom-up methods utilize individual-level data, thus accommodating individual preferences and heterogeneity within the population (Breider et al., 2006). The top-down method was employed to assess the WTP for CBRWHS based on experts' opinions, offering a broad perspective of the situation. The bottom-up approach, in contrast, was used to determine the local population's WTP for CBRWHS, as it provides a more precise representation of WTP distributions, accounting for variations in preferences, and allows for the valuation of both market and non-market goods. Moreover, we calculated several dependence coefficients for a more extensive analysis. Specifically, we computed Pearson's correlation coefficients to gage the strength and direction of linear relationships between WTP and continuous variables such as income and age and point-biserial correlation coefficients to understand the association between WTP and

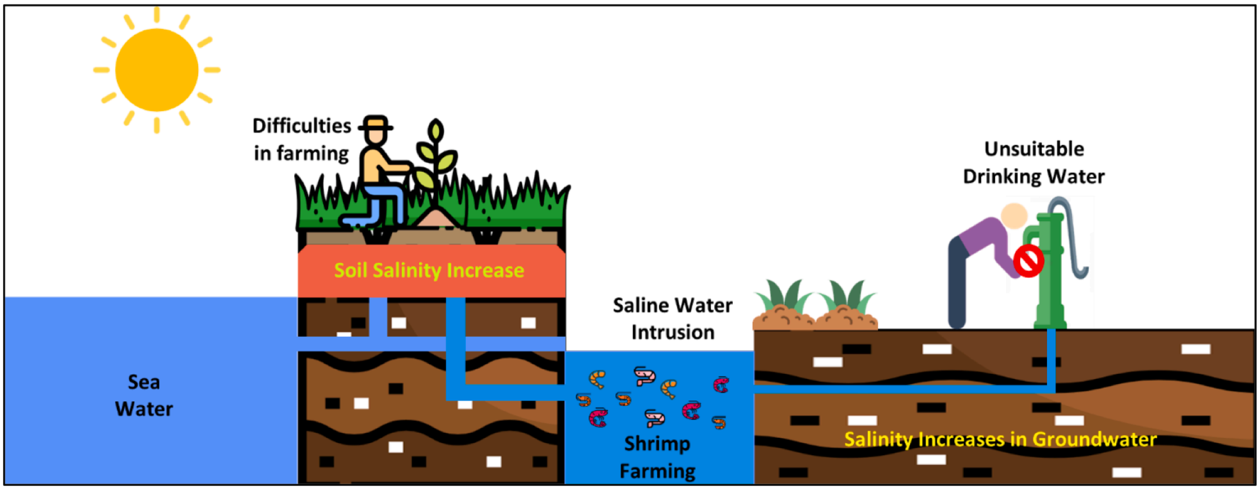

Fig. 3. Water scarcity problem in coastal Bangladesh.

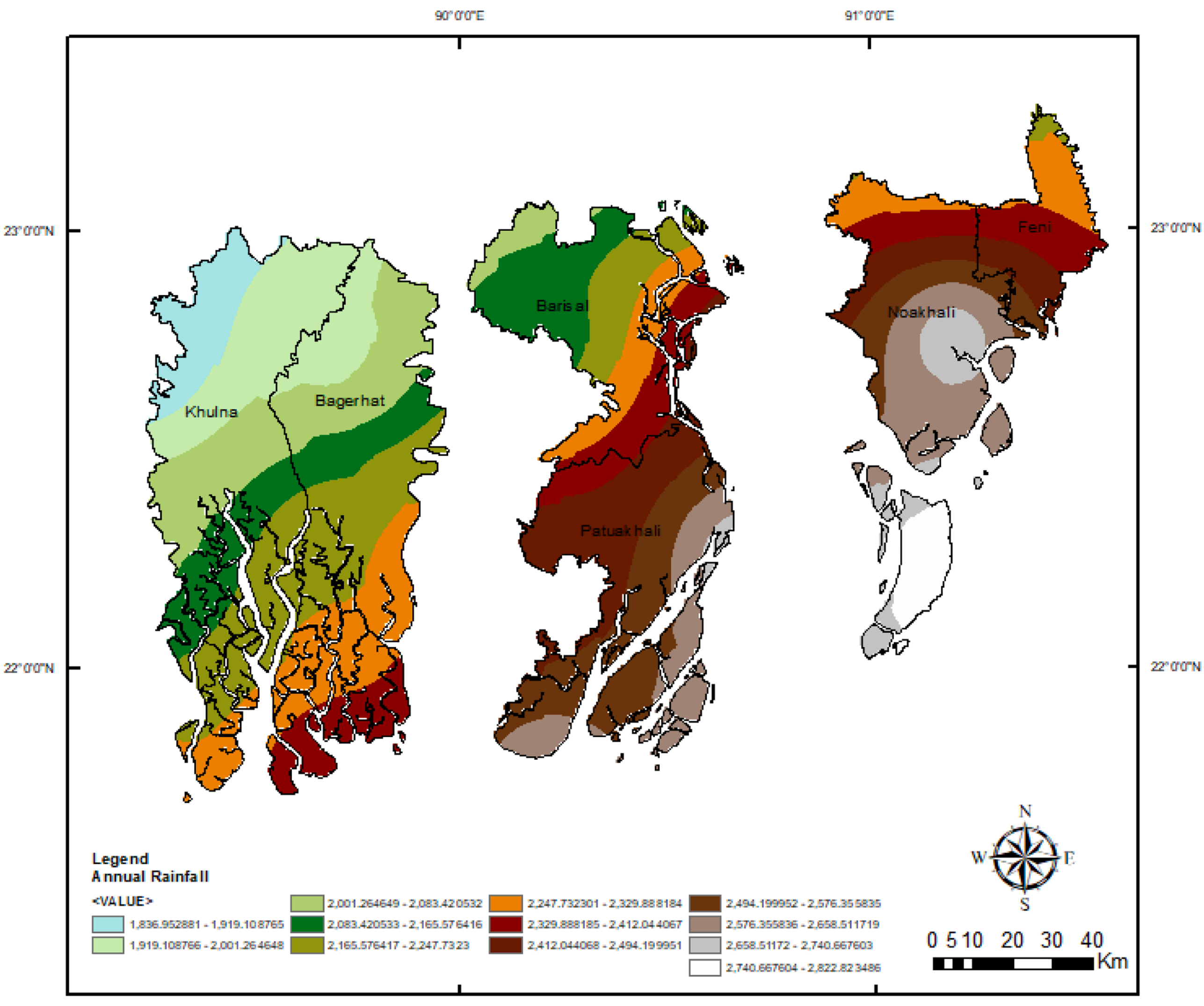

Fig. 4. Annual Rainfall 2021 of Study Area.

Fig. 5. Conduction of survey with respondents (captured by research team members).

Table 1
Information on survey sites.

District	City	Population	Gender		Annual Precipitation (mm)	Mean Annual Temperature (°C)	Number of Respondents	
			Male	Female			Officials	Local Public
Khulna	Dacope	157,489	83,193	65,756	1141	31	25	40
Bagerhat	Mongla	149,030	80,819	68,211	1934	28.9	25	50
Patuakhali	Kalapara	202,078	104,399	97,679	2657	29.3	25	40
Barisal	Banaripara	152,877	77,435	75,442	1493.2	29	25	40
Noakhali	Hatiya	341,176	174,640	166,536	3302	28.15	25	40
Feni	Shonagazi	235,229	115,680	119,549	3302	28.1	25	30

*Total surveyed population: 390, Total officials: 150, Total local public: 240.

dichotomous variables such as gender and education level. This inclusion of dependence coefficients provided a more robust analysis, shedding light on how these variables influence individuals' willingness to pay for the proposed CBRWHS. Consequently, these detailed insights should inform more nuanced policy decisions and strategies for promoting the adoption of CBRWHS (Table 1).

3. Results and discussion

3.1. Socio-Demographic profile of respondents

The sociodemographic characteristics of the coastal participants involved in this research are illustrated in Table 2. To ensure respondent anonymity and unbiased responses, the surveys deliberately excluded individual socio-demographic information, considering the limited number of competent professional specialists available at each location and institution. Table 2 reveals that the majority of coastal participants were male (89.16%), with adults (age >25) comprising the largest segment of respondents, and seniors constituted a significant minority (60.42%). Approximately 9% of the respondents were civil servants or retirees. Only 21% of the respondents were found had completed secondary education and 10.83% had achieved bachelor's degree or equivalent. The inference is that though the majority of the respondents are sufficiently grown to answer the queries sensibly due to their accumulated knowledge, comprehension, and wisdom, most of them (55%) are uneducated and working as laborers and farmers.

3.2. Perception of experts about CBRWHS

3.2.1. Perceived barriers against adoption of CBRWHS

Expert elicitation revealed that the coastal respondents in the tested communities consider the impact of natural disasters and catastrophes as the most significant hurdle to the adoption of CBRWHS (Fig. 6). The other two top barriers are financial constraints and lack of appropriate technical expertise for RWH. The experts gave similar consensus for Bagerhat and Barisal City regarding the impact of natural disasters on rainwater harvesting, along with the additional challenges of technological expertise and financial insolvency (Fig. 7). More than 85 experts deemed all specified obstacles to be of substantial or greater significance, with natural disasters, financial constraints, and technological barriers standing out as particularly prominent. The importance of administrative and maintenance factors was relatively lower but still significant. Detailed responses of the experts on city-specific obstacles illustrated in Figs. 7–11.

In response to the open-ended inquiry asking the designated experts to identify the primary reasons for the non-adoption of CBRWHS by coastal citizens, the responses were categorized into four categories (Table 3). These includes lack of information and knowledge,

Table 2
Socio-demographic characteristics of public respondents.

Parameters	Gender		Age				Literacy Level				Occupation					
Description	Male	Female	15–24	25–40	40–65	>65	No Education	Primary	Secondary	Bachelor	Civil Service or Pensioner	Self-Employed	Labor	Farmers	Unemployed	Housewife
Numbers	214	26	5	90	96	49	132	67	49	26	20	48	69	66	11	26
Percentage (%)	89.16	10.8	2.08	37.5	40	20.42	48.17	24.45	17.88	9.48	8.33	20	28.75	27.5	4.58	10.83

insufficient comprehension of water management and economy, poor management and insufficient authority, and budgetary restrictions. Most experts (64%) believe that the impact of natural disasters on water conservation and savings was the most significant impediment to RWHS adoption. Lower financial solvency and lack of required technical skills are the second and third most cited reasons for CBRWHS. Mismanagement and insufficient administrative authorities are comparatively lower yet cited as major reasons for CBRWHS non-adoption. Consistent with the previous findings, over 85 experts out of 150 recognized the significance of the identified obstacles as moderate or greater.

3.2.2. Factors for ameliorating popularity and adoption of CBRWHS

Following a comprehensive consultation with professionals regarding the obstacles that impede RWH implementation, we assessed the importance of various guidelines, plans, and strategies that have been proposed and put into practice to facilitate the implementation and propagation of CBRWHS (Neibaur and Anderson, 2016). These policies and tactics span a range of initiatives, including offering financial incentives, promoting community participation in extension programs, fostering collaboration and coordination among relevant organizations, and even mandating regulatory requirements. Given the technical nature of RWH, disseminating pertinent knowledge and guidelines is paramount for its successful implementation. Our field survey reveals that 81% of experts deem the provision of technical instructions as highly significant. Moreover, over 60% of respondents regard data transparency, the offering of free pilot projects, and the motivation of individuals toward CBRWHS as of utmost importance (Fig. 11). The encouragement for individuals to install RWHS is identified as the second most vital factor by those with an opinion on the subject.

Developing a transparent platform for data provision and initiating RWHS pilot projects - both enhancing the visibility and demonstrability of this innovative technology - is considered the third and fourth most essential factors, respectively. These elements play a pivotal role in the adoption of such novel technology. Direct exposure to RWHS could potentially quadruple adoption rates (Jafari et al., 2016). While financial support, maintenance services, and increased interagency collaboration have garnered less emphasis compared to other needs, over 75% of participants still ranked these aspects as moderately to highly significant. Given the immense importance of water resources and their current precarious status across the entire research region, coupled with the fact that securing financial aid, maintenance services, and fostering interagency collaboration are time-consuming endeavors, experts tend to prioritize quick-result solutions. Despite high illiteracy rates, the region boasts a solid Information and Communication Technology (ICT) development index. This makes creating and disseminating RWHS guidelines relatively straightforward, especially in urban coastal cities. Integrating the internet and social media in presenting technical guidelines and RWHS pilot projects can substantially accelerate the adoption of CBRWHS, particularly when paired with monetary incentives and promotional activities. Technical assistance, rewards, and motivation are all crucial for public adoption of RWHS, yet regulations mandating RWHS installation in both new and existing buildings also hold significant importance (Castonguay et al., 2018). In numerous countries worldwide, such as the United Kingdom (Ward et al., 2013), Australia (Chubaka et al., 2018), India (Solanki, 2016), Brazil, Germany (Teston et al., 2018), Japan (Furumai et al., 2008), Malaysia (Lani et al., 2018), Kenya (Mutua, 2010), South Korea (Han, 2013), Mexico (Fuentes-Galvánet al., 2018), and the United States (Meehan and Moore, 2014), RWH is a construction prerequisite for new structures. The successful realization of RWHS heavily relies on the enhancement of technical capabilities.

Considering all factors influencing the incentives to adopt RWHS, according to the perspectives of all official respondents, these have been illustrated in Figs. 14–20. Fig 13 shows that 89% of experts rank this element as highly to extremely significant, with experts from Barisal and Bagerhat asserting its paramount importance for CBRWHS (Fig. 14).

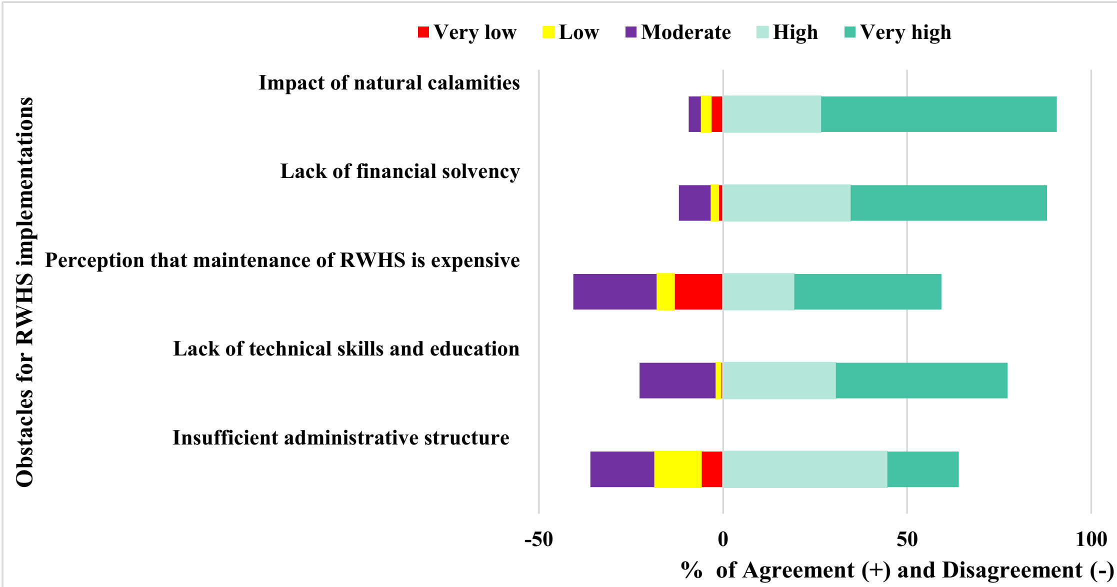

Fig. 6. Assessment of principal challenges to the implementation of RWHS, based on expert perspectives.

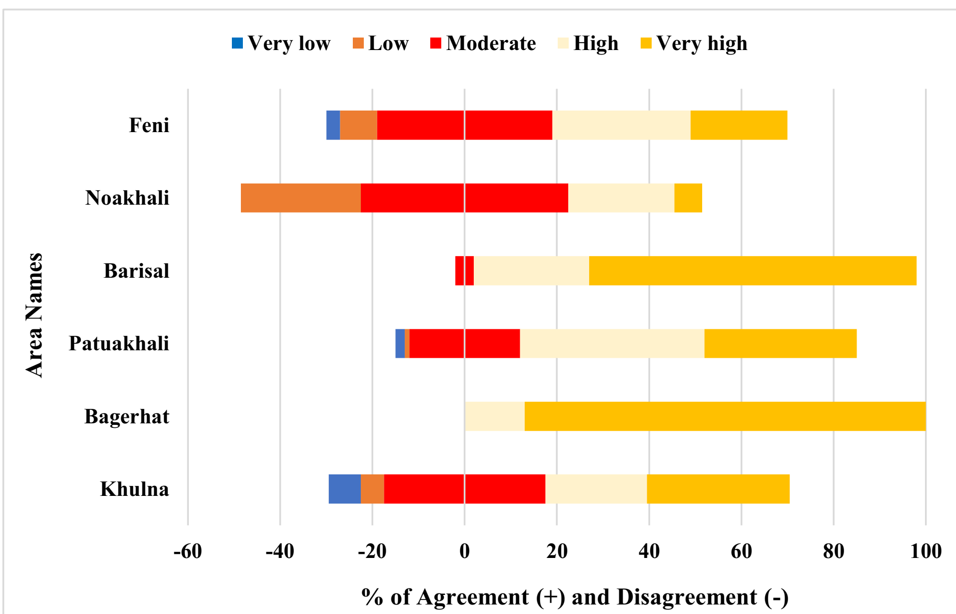

Fig. 7. Expert perspectives on the effects of natural disasters.

3.3. Community viewpoints towards RWHS

3.3.1. Public knowledge, perception and attitudes towards domestic water supply

Insights were collected from local residents regarding their consciousness and perceptions about the quality of water provided within the study area. Findings from the field survey, which encompassed aspects such as municipal water supply, water quality, and pricing, are outlined in Table 4. A prominent concern voiced by respondents was the heightened saline levels in local ponds and natural water sources. These respondents also reported that the generally poor quality of supplied water led to frequent experiences of water scarcity. In addition, inconsistencies in the availability of supplied water were reported, with approximately 62% of respondents citing the relatively high price of water. Notably, 89% of the local respondents refrain from utilizing water-saving appliances and equipment. The study further disclosed that, according to 74% of the respondents, the local water supply fails most of the time. Consequently, coastal residents' resort to using saline water for drinking and other residential uses due to limited potable and usable water availability. This dependency on saline water stems from the poor quality of domestic water sources. A substantial 64% of the surveyed population perceived domestic water sources as deficient quality. However, it is essential to note that only 37% of the respondents reported actively engaging in water conservation practices, such as utilizing pottery, tanks, and other containers, with many opting for rainwater harvesting. The evidence suggests a compelling need to advocate for water conservation efforts and the adoption of CBRWHS.

3.3.2. Experience with RWH as a significant source of primary water: familiarity, technological comprehension, and desire to employ CBRWHS

Table 5 summarizes the experiences and interests of local residents regarding CBRWHS. The data shows that around 55% of respondents

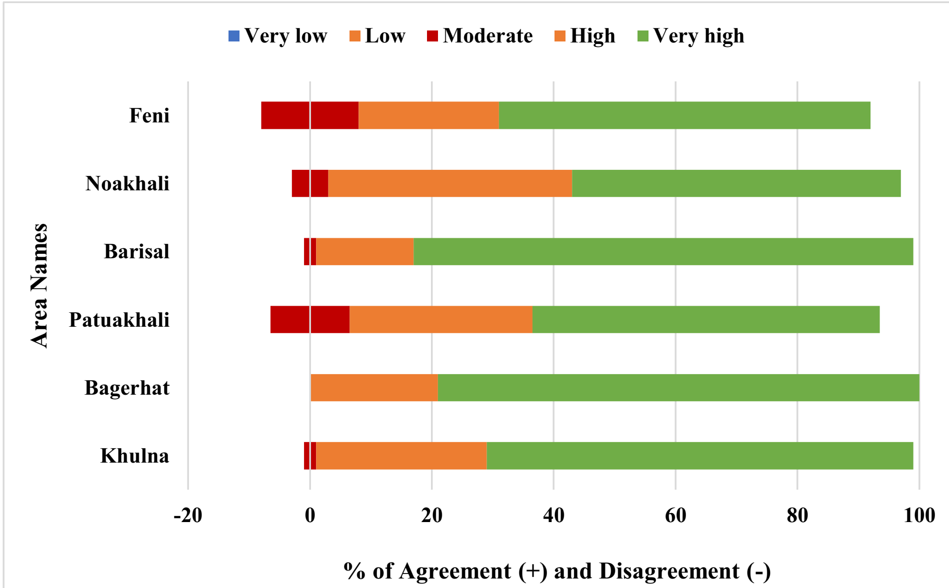

Fig. 8. Expert analysis on the prevalence of financial insolvency.

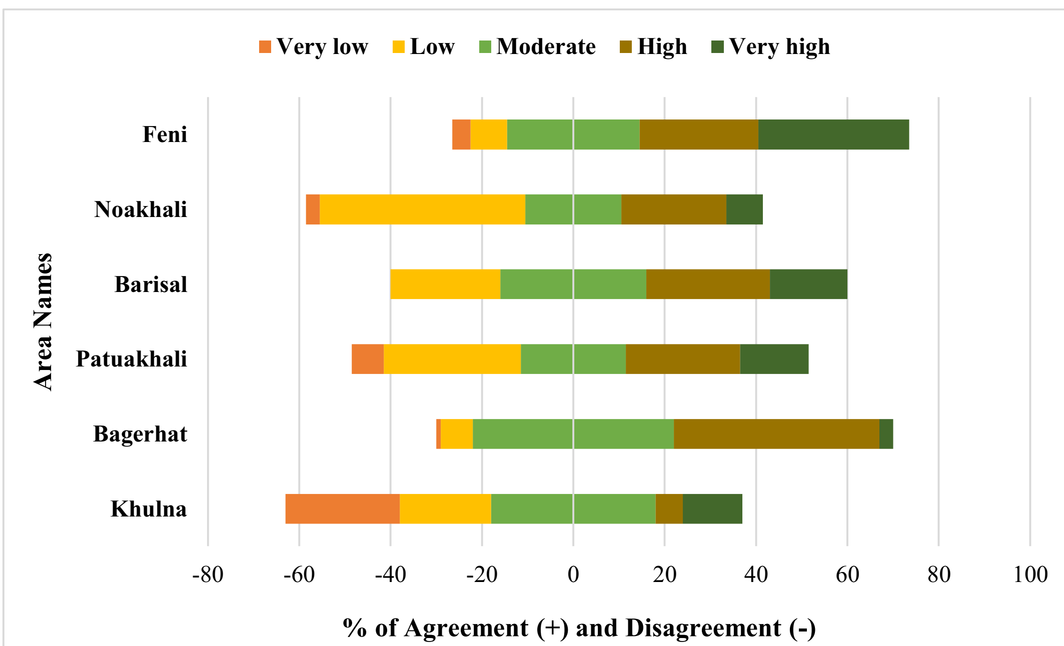

Fig. 9. Expert perception of the costliness of RWHS maintenance.

have had firsthand experience observing rainwater harvesting. Of all the participants from the six cities, those from Barisal reported the highest number of individuals with firsthand observation of its use. Furthermore, approximately 64% of respondents voiced their interest in employing CBRWHS. Despite the majority of respondents expressing interest or already using CBRWHS, a negligible 1% deemed it unnecessary; intriguingly, these respondents were from Feni and Patuakhali. Respondents were also asked about their observations of neighbors or friends utilizing CBRWHS, with nearly half reporting they had seen acquaintances use this system for water conservation. Approximately 78% of respondents expressed their readiness to install individual RWHS. All respondents from Bagerhat and 90% from Barisal City were interested in establishing individual RWHS, whereas only 48% of respondents from Feni and 60% from Noakhali displayed readiness. Fig. 12 illustrates existing CBRWHS in the coastal cities of Bangladesh.

Fig. 21 discloses that 38% of respondents from Noakhali and 24% from Feni City reported having no knowledge about individual RWHS construction, while 67% of respondents from the Bagerhat district claimed to have sufficient knowledge. Additionally, about 59% of respondents from Khulna and 50% from Feni believe that the installation of RWHS would be simple (Fig. 22). However, the majority of respondents from all surveyed cities perceived the installation process as complex. Interestingly, Fig. 23 shows that a notable proportion of respondents from Khulna, Patuakhali, Noakhali, and Feni City indicated a lack of knowledge about the maintenance frequency of RWHS. This lack of knowledge aligns with the expert assessment that the absence of

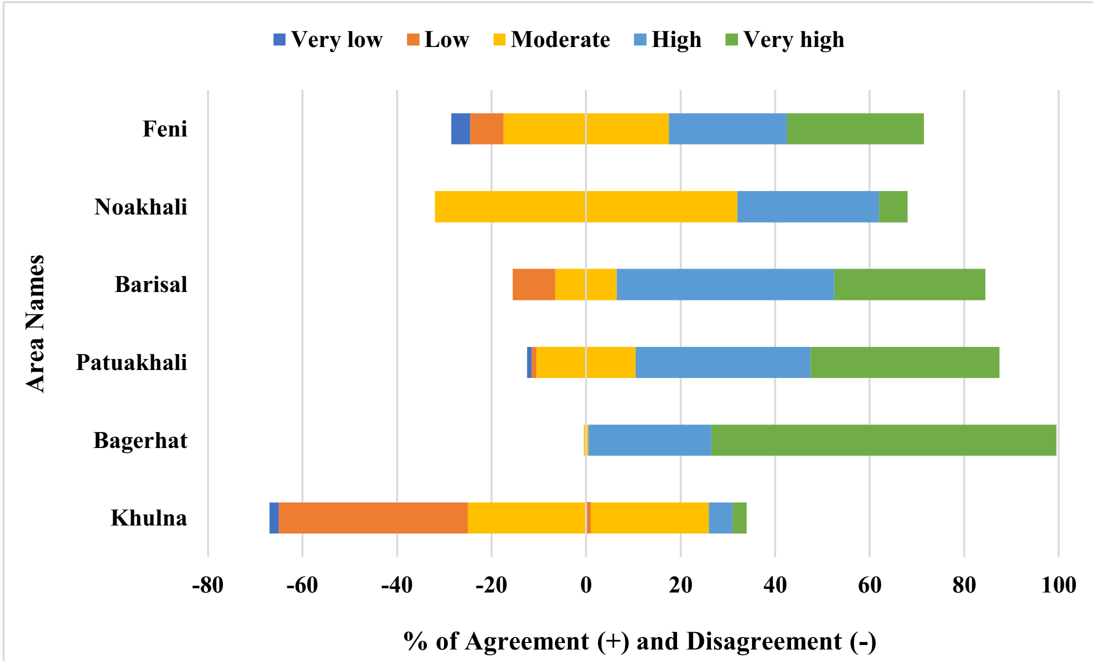

Fig. 10. Expert view on the deficiency of technical skills and education.

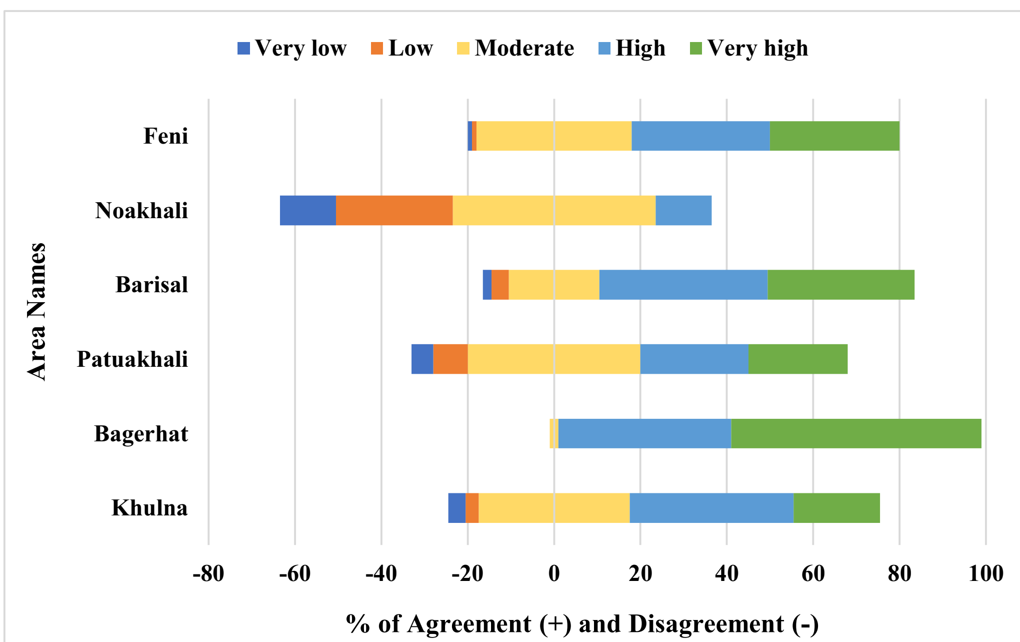

Fig. 11. Expert commentary on insufficient administrative structures.

technical guidelines hinders the public's adoption of RWHS. Personal knowledge is a key step in disseminating innovative technology (Rogers, 2010), and in Bangladesh, currently, construction materials needed for rainwater harvesting are currently easily accessible, and the installation and operation processes have been simplified. However, the primary challenge remains in disseminating knowledge and technical expertise.

3.3.3. Perceived quality of harvested rainwater

Rainwater finds utility in a plethora of applications, including drinking, cooking, dishwashing and laundry, flushing toilets, bathing, and watering plants (Bello and Nike, 2015). In order to foster sustainable adoption and utilization of CBRWHS, it becomes crucial to address public apprehensions related to the quality of harvested rainwater. Community members were thus surveyed about their perceptions of the quality of collected rainwater as compared to domestic water, compliance with rainwater quality standards, compatibility of use, and willingness to employ rainwater for various purposes. Table 6 presents a summary of the survey findings.

Table 6 reveals that 41% of the participants voiced uncertainty regarding the quality of harvested rainwater, with the majority hailing from Khulna (56%). While a significant proportion of respondents from Bagerhat (69%), Barisal (58%), and Noakhali (44%) opined that harvested rainwater is more convenient than local or supplied water, only a

Table 3
Most significant obstacles to RWH adoption are based on experts' opinions in the country.

Category of reasons	The highlighted reason (frequency)	Frequency	No.	Percent
Insufficient knowledge and information	Insufficient information about RWH	4	103	68.6%
	Absence of operational pilot RWH systems	10		
	Insufficient RWH education and instruction	21		
	No previous experience with RWH	13		
	Lack of understanding regarding RWH installation and use	26		
	Lack of technical knowledge concerning RWH	29		
Inadequate understanding of water conservation and economization	Lack of water conservation	8	134	89.3%
	RWH-related cultural and religious concerns	0		
	No moral obligation to preserve water	14		
	Absence of environmental concern	12		
	Unwillingness to conserve water	5		
	Preservation of water is not seen as a human obligation	4		
	No genuine awareness of water scarcity	9		
	Consideration that water is an infinite resource	4		
	Inattention to conservation practices in the region	21		
	No importance is given to water conservation	12		
	Rainwater is typically viewed as an irritation and a liability.	3		
	The benefit of water conservation is not recognized.	21		
	It is not considered that rainwater is clean and safe water.	10		
	RWH is devoid of any ambition	11		
Mismanagement and insufficiency of authorities	Absence of an integrated and sustainable approach	19	135	90%
	Authorities' negligence regarding water issues	15		
	Authorities' deficiency	4		
	Authorities' disfunction	18		
	Lack of a specific department for RWH	12		
	Lack of sufficient technical support availability	16		
	Authorities' absence of confidence in RWH	5		
	Absence of government guidance and support for RWH	4		
	Authorities' inadequate understanding of RWH systems	11		
	Relative paucity of cooperation and collaboration within and between pertaining governmental entities	31		
Financial constraints	Insufficient allocation of government funds for RWH;	13	87	58%
	Unsustainable for many individuals	31		
	Very costly	0		
	Not budget friendly when compared to the cost of water	0		
	No state aid from the government	37		
	Reduced water prices	6		

minor fraction from Khulna (5%), Patuakhali (15%), and Feni (30%) concurred with this viewpoint. About 55% of respondents confessed ignorance regarding the suitability of harvested rainwater. Nevertheless, among those who do collect rainwater, 43% utilize it for cooking and 44% for drinking. Over half the coastal populace in Bagerhat and Barisal attested that the quality of harvested rainwater surpasses that of domestic water, crediting its traditional usage in some rural communities. Among non-harvesters, 39% expressed a willingness to collect rainwater for drinking, while 26% indicated an intent to employ it for cooking.

Despite rainwater being deemed relatively safe and suitable for consumption with minimal treatment, the majority of respondents harbored reservations about its purity. However, the experiences of communities in Bagerhat and Barisal, coupled with numerous worldwide studies and feedback from RWHS adopters, indicate satisfaction with the quality of harvested rainwater (Ahmed et al., 2017). Given the high potential for water contamination, especially when rainwater is stored in different types of tanks or rooftop catchments (Fig. 24), proper disinfection cannot be overstated (Starovoytova et al., 2016). Despite adequate treatment, the adoption of CBRWHS within the coastal community remains stymied by the challenges of technical skills and financial constraints.

Following the analysis of coastal respondents' perceptions regarding the use of harvested rainwater, a comparison between public willingness and suitability perception for varied services was conducted, with results presented in Fig. 25. A notable correlation exists between the perception of rainwater's compatibility for application and the inclination to utilize it across various purposes. This discovery aligns with research undertaken in Iran and Scotland, examining attitudes and perceptions towards domestic rainwater harvesting (Egyir et al., 2016; Sheikh, 2020). The findings corroborated the observed pattern, demonstrating a strong link between an individual's readiness to adopt rainwater harvesting practices for domestic use and their actual likelihood of doing so. Furthermore, the study underscored the suitability of rainwater for most domestic applications. To guarantee the success and sustainability of community-based rainwater harvesting, adherence to guidelines established by the World Health Organization (WHO) concerning the quality of water used for drinking, cooking, and personal hygiene becomes paramount (WHO, 2011).

3.3.4. Perceived economics of CBRWHS

RWH systems entail two types of costs: installation costs, which are a one-time expense (Dijk et al., 2020), and ongoing operational and maintenance costs. While prior studies primarily focus on the financial evaluation of RWHS regarding capital expenditures and technology (Amos et al., 2020), a comprehensive analysis of all significant cost components remains crucial. This research scrutinizes how the coastal public perceives capital costs, maintenance costs, price efficiency, and their propensity to invest in RWHS. Table 7 summarizes the coastal public's views on the financial performance indicators of RWHS.

Table 7 reveals that 70% of respondents estimate RWHS installation cost to be between \$150 and \$300, with 15% projecting a cost exceeding \$300, averaging approximately \$225. Regarding their readiness to shoulder the expenses linked to rainwater harvesting systems, approximately 23% of coastal respondents expressed a financial inability, and 35% showed interest conditional on subsidies or favorable financing options. Only 8% were prepared to personally sponsor RWHS, with expenditures ranging from \$300 to \$500, while 38% agreed to install IHB RWHS at an investment of around \$150. No participant exhibited a willingness to spend more than \$500 on RWHS installation. An

Table 4
Knowledge, perceptions, and attitudes regarding the supply and uses of domestic water (Unit:%).

Question/Criteria	Response options	Khulna	Bagerhat	Patuakhali	Barisal	Noakhali	Feni	All
Local water supply Failure	Yes	88	90	68	74	68	50	**74**
	Low pressure in dry seasons	0	0	3	3	20	30	10
	Occasional disruption in summer	0	0	5	1	5	10	4
	Water rationing in dry seasons	12	10	24	22	7	0	13
Municipal water quality	Very low	69	54	69	66	69	60	**64**
	Low	25	40	30	44	29	20	31
	Moderate	6	6	1	0	1	10	4
	High	0	0	0	0	1	10	2
	Very high	0	0	0	0	0	10	1
Municipal water pricing	Very low	0	0	0	0	0	0	0
	Low	0	0	0	0	0	0	0
	Moderate	31	10	47	31	25	60	34
	High	65	80	43	69	72	40	**62**
	Very high	4	10	10	0	13	0	6
	Yes	39	79	49	32	5	20	37
Utilizing water-saving appliances and equipment	No	90	99	85	80	92	90	**89**
	Yes	10	1	25	20	8	10	13
Perception of water conservation	Never	29	40	14	51	59	30	**37**
	During droughts	50	32	41	23	18	50	35
	During water rationing periods	18	20	33	22	9	20	20
	Sometimes	2	7	5	2	8	10	5

Table 5
Knowledge, expertise, and a determination to employ RWHS (Unit:%).

Question/Criteria	Responses	Khulna	Bagerhat	Patuakhali	Barisal	Noakhali	Feni	All
Observing RWHS usage directly	Yes	53	100	38	**79**	27	35	**55**
	No	47	0	62	21	73	65	45
Familiarity with or interest in RWHS	Yes, previously	11	3	19	9	2	10	9
	Yes, currently	71	**94**	33	87	73	28	**64**
	Not yet, but interested	5	0	15	2	3	30	9
	Not yet, not interested	1	0	2	1	4	0	1
	I had no idea that this could be beneficial	12	3	30	1	18	29	16
	I do not consider that it is required.	0	0	1	0	0	3	1
Do you have any acquaintances or relatives who use RWHS?	No	53	0	77	12	68	**88**	**50**
	Yes	47	100	23	**88**	32	12	**50**
Commitment to use RWHS collected water	Yes, I use it currently	29	53	25	75	32	20	39
	Yes	68	41	**69**	25	68	52	**54**
	Not sure	2	6	6	0	0	25	7
	No	1	0	0	0	0	3	1
Readiness to install RWHS in the case of financial assistance	Not sure	20	0	12	10	37	27	18
	No	0	0	1	0	3	25	5
	Yes	80	100	**87**	90	60	48	**78**

Fig. 12. Illustration of existing CBRWHS in the coastal communities of Bangladesh.

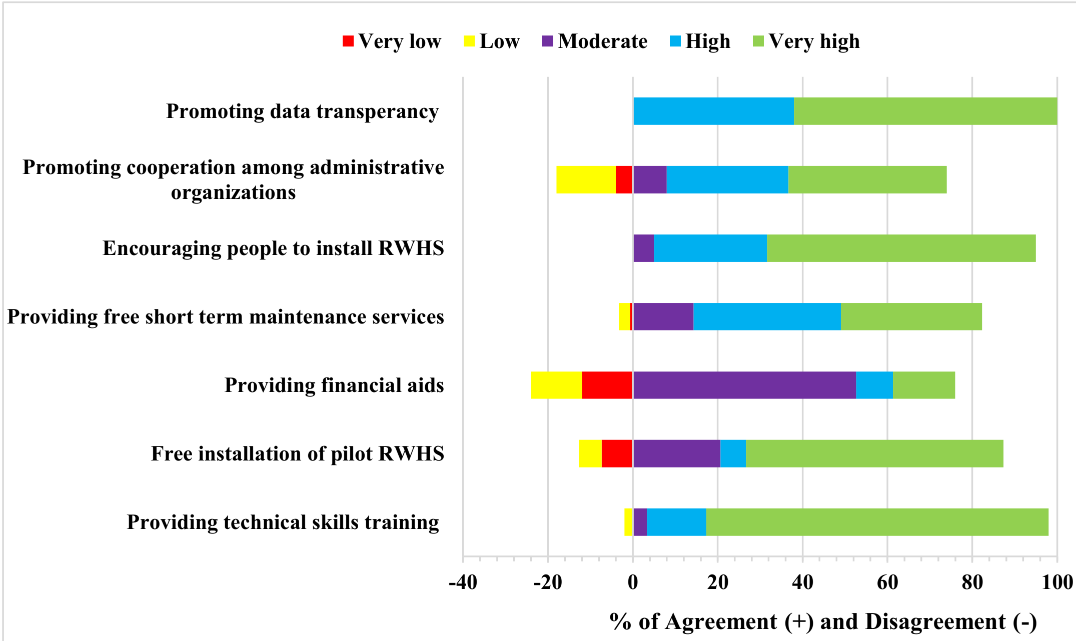

Fig. 13. Experts' evaluation of incentives to encourage RWHS adoption.

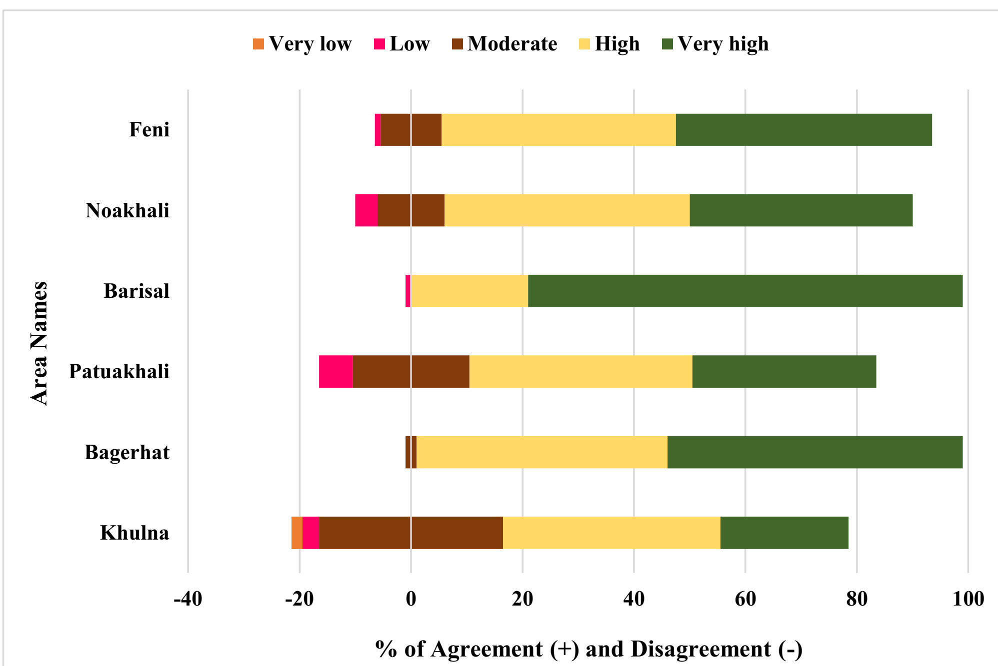

Fig. 14. The facilitation of technical skills training, as per expert insights.

estimated 72% of respondents suggested that the comparative cost of RWH, in relation to overall house construction, exceeds 5%. Concerning the frequency of required maintenance activities, 89% of respondents confessed ignorance of the actual annual maintenance costs. In terms of cost-effectiveness, a majority (65%) view domestic RWHS as somewhat cost-effective.

3.3.5. *Perceived institutional characteristics of CBRWH*

Despite rainwater harvesting technology's relatively straightforward installation, operation, and maintenance, continuous innovation and improvement are essential for maintaining its acceptability, effectiveness, and sustainability (Nijhof et al., 2010). Hence, robust institutional support is crucial for ensuring the long-term sustainability of established RWHS. Implementing appropriate organizational and institution-based frameworks is vital to foster technical knowledge dissemination, establishing extensive institutional support programs, and enhancing trust in CBRWHS.

Fig. 26 illustrates the respondents' perceptions regarding institutional aspects of CBRWHS adoption in the community. It is clear that in five out of six cities, fewer than 20% of respondents believe that specialized organizations play a significant role in RWHS adoption. This insight underscores the deficiency in institutional engagement in

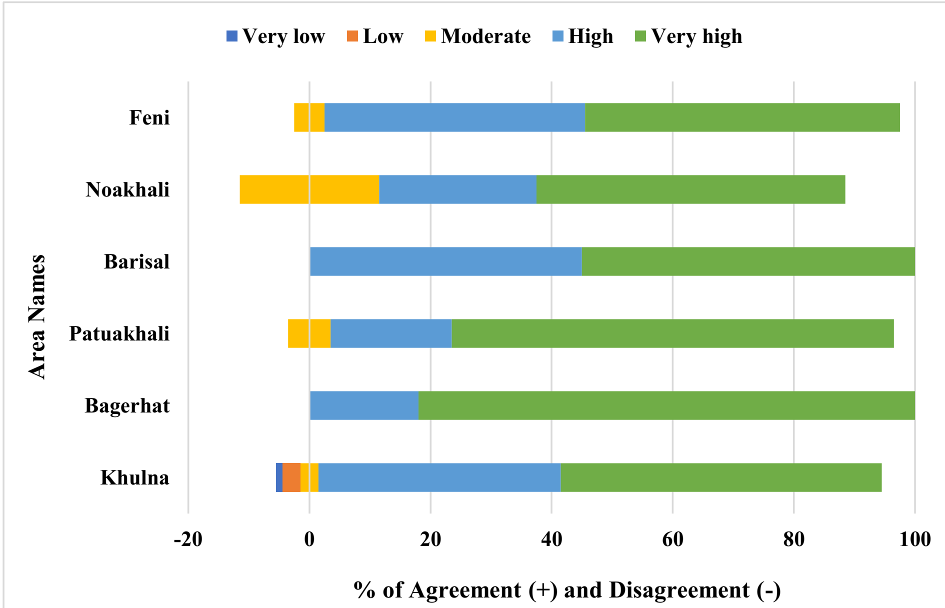

Fig. 15. Expert opinion on the impact of free RWHS pilot installation.

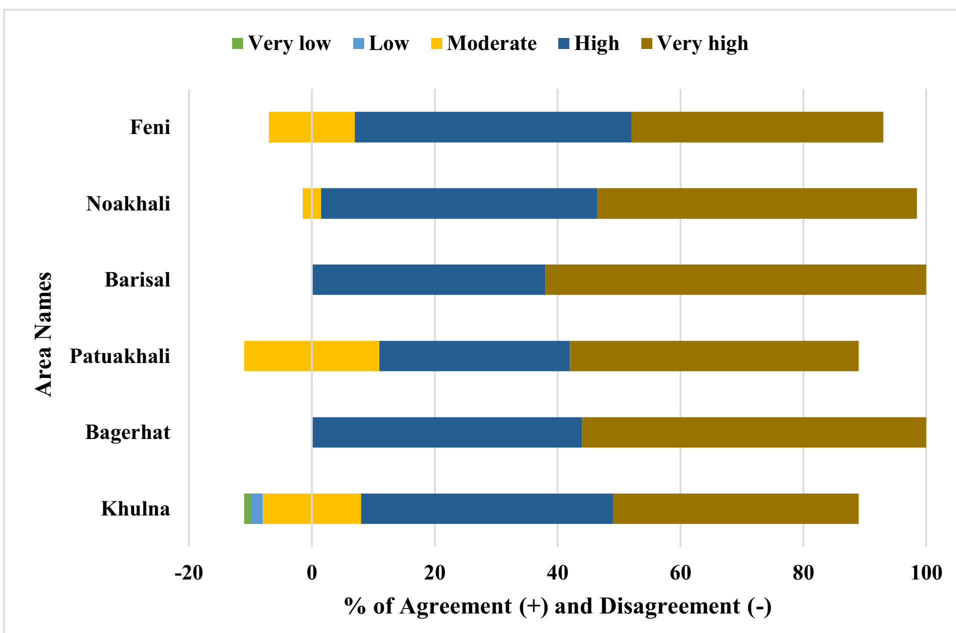

Fig. 16. Expert assessment on the effectiveness of financial aid provision.

managing rainwater harvesting systems. Notably, nearly 50% of respondents from Bagerhat acknowledge the potentially substantial impact of specialized organizations. Over 67% of respondents across all cities advocate for a collaborative approach among affluent individuals, municipalities, and water authorities to implement rainwater harvesting systems, emphasizing the importance of partnerships and shared responsibilities in promoting the widespread adoption of RWHS.

3.3.6. *Perceived constraints, issues, and subsidies for CBRWHS adoption*

RWH is a highly beneficial alternative technique for water supply, providing advantages to the community, the economy, and the environment (Lani et al., 2018). Consequently, communities should consider their socioeconomic, institutional, and environmental roles to conserve freshwater resources and reduce the escalating demand for traditional water sources. For this, several crucial steps need to be taken, including evaluating the perceived barriers, identifying and improving the techniques to foster technology acceptance, and implementing effective awareness generation and promotion strategies.

Before investigating respondents' motivations for installing and using RWHS in this study, we diligently examined the obstacles, concerns, strategies, and methods for increasing awareness (Fig. 28, Table 8). Also, a seasonal calendar was prepared in collaboration with the participants (Fig. 27). More than 65% of the overall coastal respondents consider a lack of knowledge and information along with economic constraints, as the top barriers against installing RWHS. Lack of interest and higher installation costs were ranked as the third and

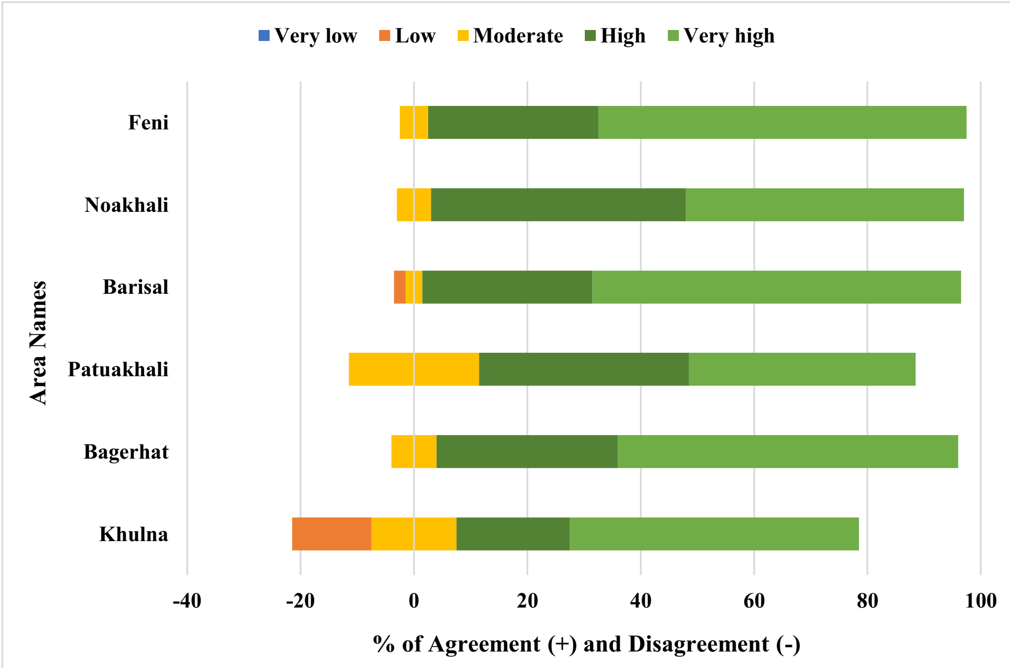

Fig. 17. Experts' perspective on offering complimentary short-term maintenance services.

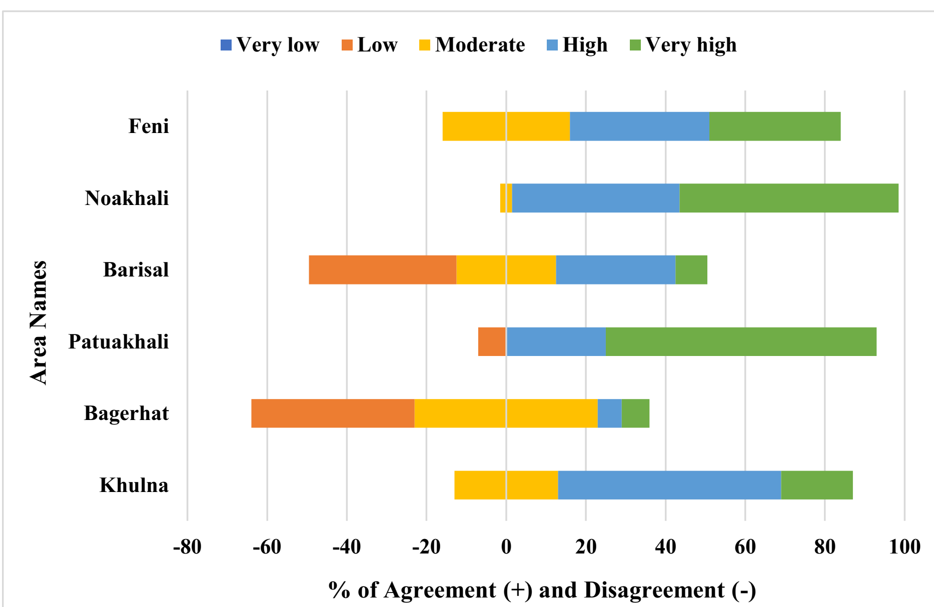

Fig. 18. Strategies to motivate public interest in RWHS installation: An expert view.

fourth impediments, respectively, while lack of space received the least votes. This indicates that space allocation is not a major concern for installing RWHS. "Drugs and Smuggling" is an issue that the community members raised during our interactions with them. Although it might seem unconnected to a study focusing on RWHS, it is a significant factor affecting these regions' livelihoods and socioeconomic dynamics. Drug use and smuggling incidents tend to fluctuate seasonally, impacting aspects like local employment, migration patterns, and overall community well-being. These factors indirectly influence the community's ability and willingness to adopt and maintain RWHS.

Insufficient understanding of the technology, significance, and value of RWHS is the primary reason why people fail to perceive the need for RWH. To address this, it is crucial to disseminate adequate information and technical expertise on the various elements of RWHS through establishing technical guidelines, training, and public education (Shalamzari et al., 2016). Financial and technical aspects were found to be the primary concerns for all respondents, with quantity and space requirements being secondary and less significant. Among the respondents, 50% believed providing financial assistance through governmental incentives was the most influential technique to promote RWHS adoption.

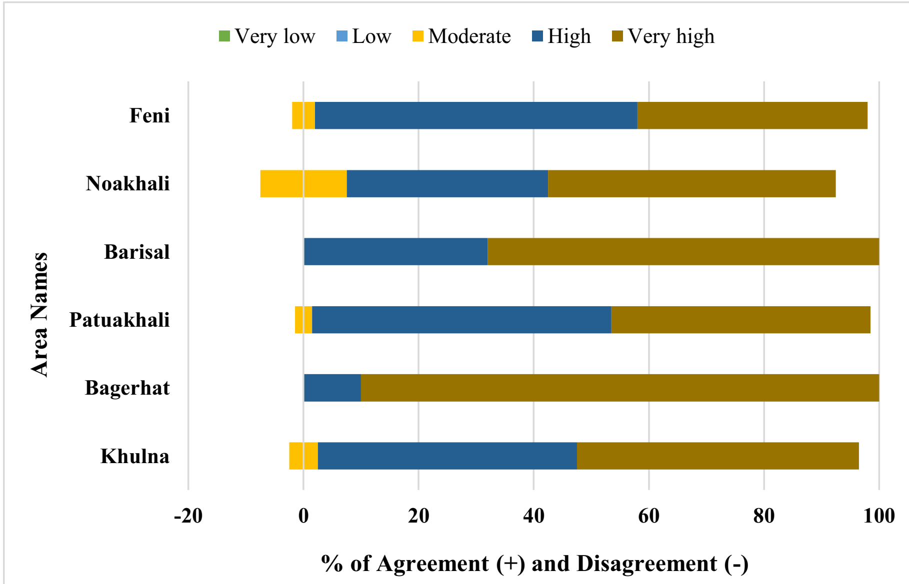

Fig. 19. Expert advocacy for fostering collaboration among administrative bodies.

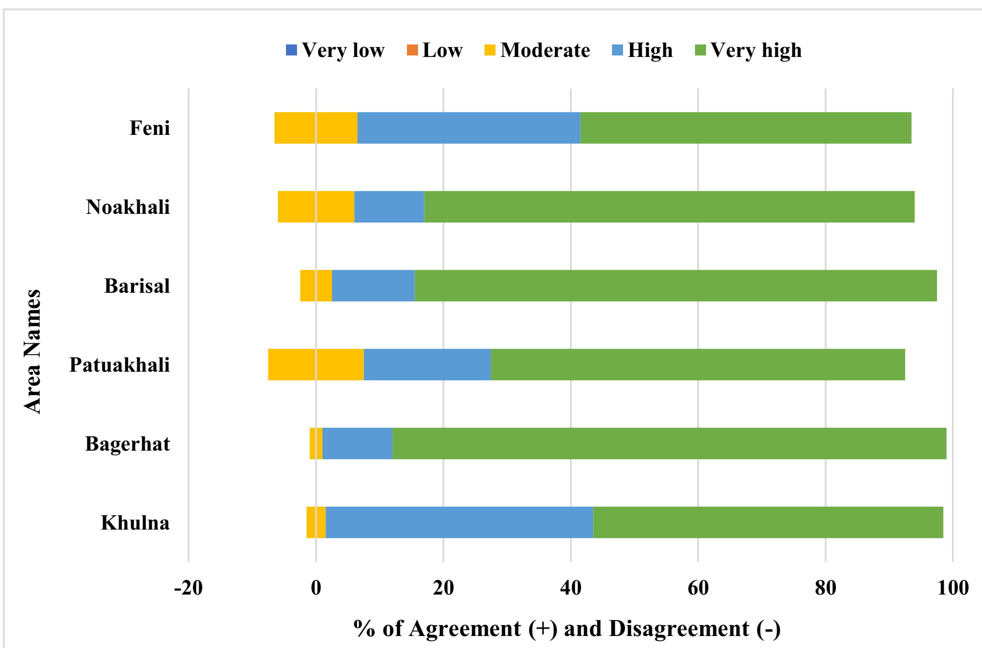

Fig. 20. Expert perspective on the promotion of data transparency.

Table 8 highlights that educational workshops aimed at improving technical skills were deemed the most effective means of dissemination and awareness-raising. Almost 42% of the respondents affirmed that improving technical skills can help them promote the installation of RWHS. Given the coastal population's limited access to education and their precarious financial situation, it becomes evident that without adequate technical knowledge of the installation, operation, and maintenance processes, it is challenging for them to adopt CBRWHS. Previous pilot projects conducted by reputable NGOs were unsuccessful in the long run, as the coastal communities struggled to ensure proper maintenance and lacked the financial means to hire technicians regularly for monitoring. In terms of incentives, the respondents expressed the need for cost-effective CBRWHS solutions to ensure long-term sustainability.

4. Conclusion

The unique challenges coastal communities face concerning freshwater accessibility arise from geographical features, frequent natural disasters, excessive soil salinity, and the prevailing impacts of climate change. These communities encounter difficulties in securing their daily water requirements. Therefore, it becomes imperative to introduce sustainable and locally feasible solutions to ensure consistent freshwater availability. Installing CBRWHS can potentially become an effective freshwater source in such regions, furnishing safe water for domestic and agricultural usage. Recognizing the users' knowledge, opinions, attitudes, and perceived value of this innovative technology is vital for facilitating its adoption process. Consequently, the feasibility of CBRWHS implementation in the coastal regions of Bangladesh was

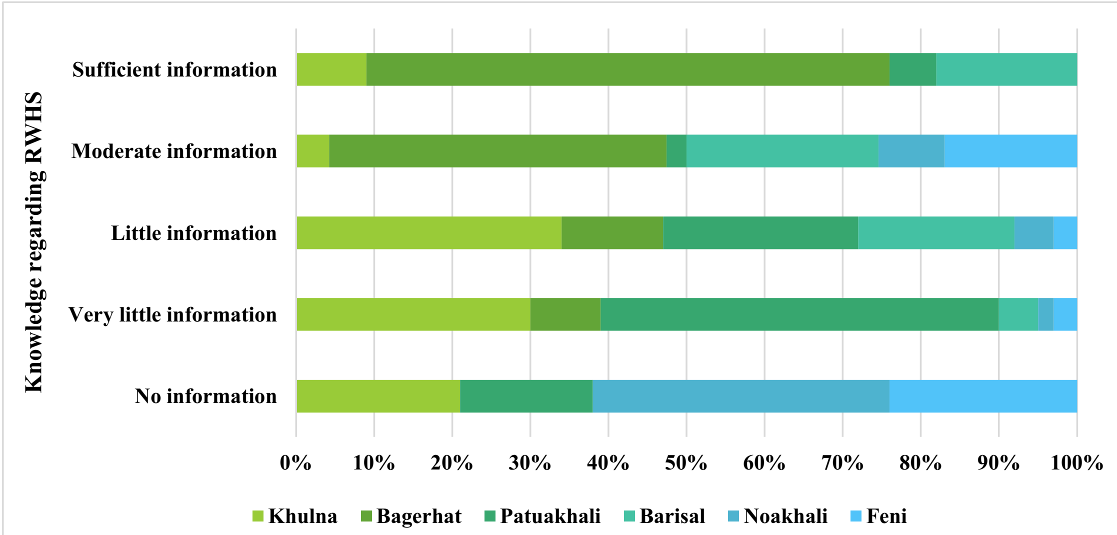

Fig. 21. Expert insights on the knowledge required for RWHS construction.

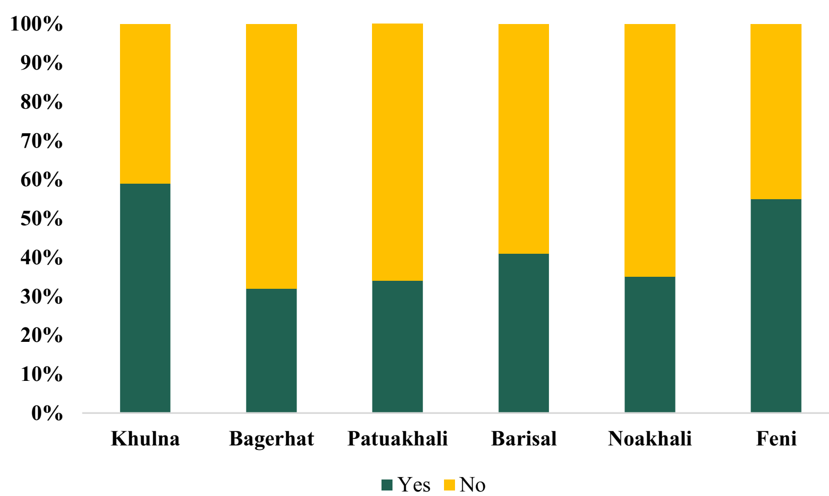

Fig. 22. The perceived ease of RWHS installation according to experts.

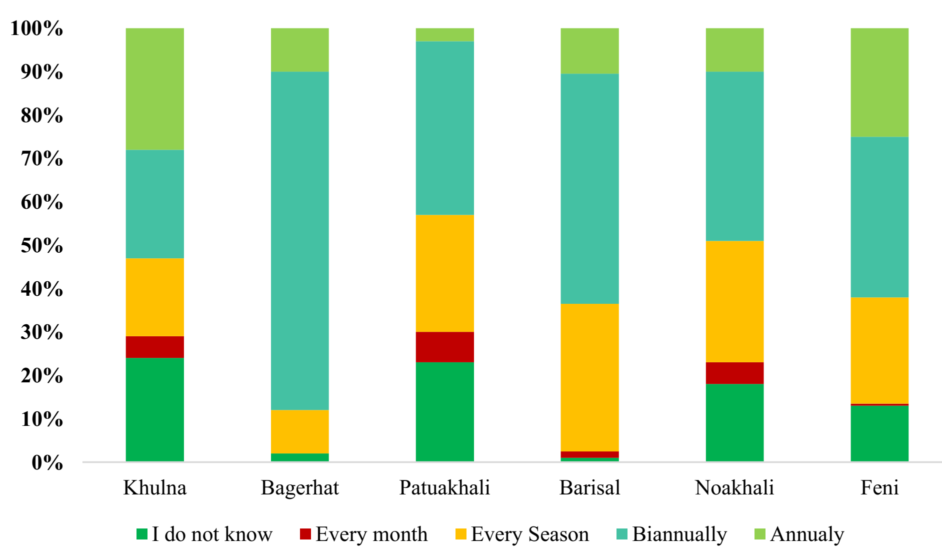

Fig. 23. Expert analysis on the anticipated frequency of RWHS maintenance.

Table 6
Potential application of collected rainwater (Unit:%).

Question / Criteria	Response options	Khulna	Bagerhat	Patuakhali	Barisal	Noakhali	Feni	All
Rainwater's quality in comparison to municipal water	Not sure	56	23	70	17	31	48	41
	No difference	6	0	0	10	16	9	7
	There is no difference after disinfecting.	2	2	2	0	9	4	3
	Worse than municipal water	31	6	13	15	0	9	12
	Convenient than local water	5	**69**	15	**58**	**44**	30	37
The suitability of collected rainwater for various uses	I do not know exactly	**63**	**52**	**62**	**24**	**53**	**76**	**55**
	It is not suitable for any use	2	0	0	0	3	1	1
	For outdoor cleaning	3	1	12	19	3	2	7
	For toilets and flush tanks	15	3	1	5	1	3	5
	With minimal pretreatment for laundry and dishwashing	0	16	3	21	7	5	9
	After treatment and filtration for culinary consumption and drinking	17	28	22	**31**	33	15	24
Utilization compatibility of collected rainwater	Irrigating	2	0	0	0	0	0	0
	Toilet and flush tank	1	0	0	8	0	0	2
	Bathing	0	0	0	11	0	0	2
	Washing Clothes	12	0	19	0	0	0	5
	Washing Dishes	18	1	0	5	0	0	4
	Cooking	**49**	60	**67**	**49**	23	10	43
	Drinking	**18**	**39**	14	27	77	90	**44**
Willingness to utilize harvested rainwater for	Irrigating	0	0	0	0	0	0	0
	Toilet and flush tank	20	7	23	15	5	37	18
	Bathing	3	0	0	0	1	11	3
	Washing Clothes	8	0	5	11	18	28	12
	Washing Dishes	5	0	0	0	9	6	3
	Cooking	18	28	**41**	**37**	16	13	**26**
	Drinking	**46**	**65**	31	37	**51**	5	**39**

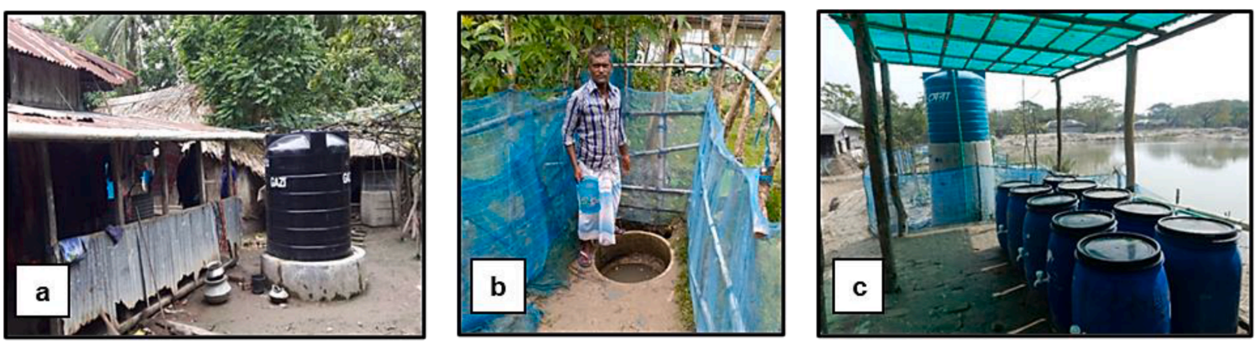

Fig. 24. Storage of harvested rainwater for drinking purposes in the coastal communities of Bangladesh.

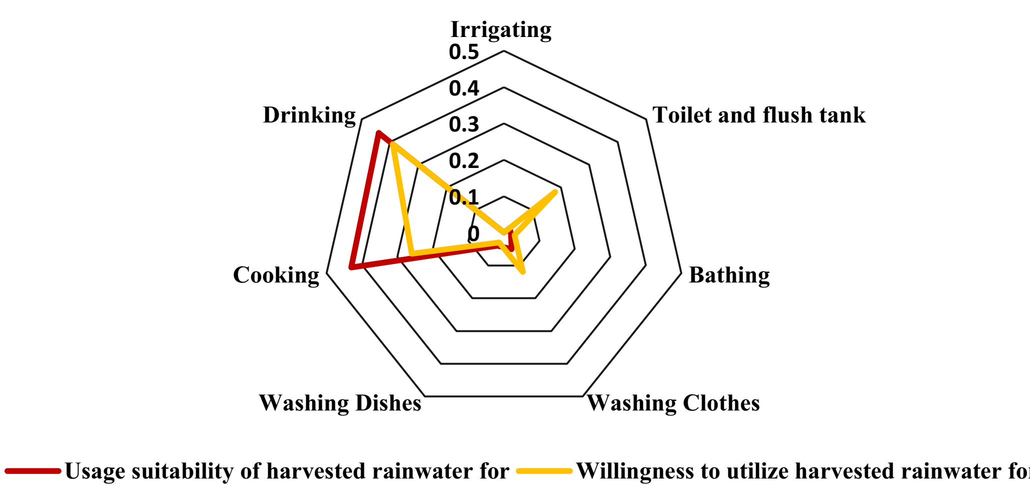

Fig. 25. Comparison of perceptions of applicability and tendency to utilize CBRWHS.

Table 7
Economic considerations of CBRWHS (Unit:%).

Question/Criteria	Response options	Khulna	Bagerhat	Patuakhali	Barisal	Noakhali	Feni	All
Capital cost of CBRWHS installation per 750-liter tank	< 150 USD	0	8	0	17	20	10	9
	150 –300 USD	67	90	88	82	60	68	76
	300–500 USD	30	2	12	1	19	22	14
	500–1000 USD	3	0	0	0	1	0	1
	>1000 USD	0	0	0	0	0	0	0
Willingness/readiness to pay for/invest in CBRWHS	I cannot afford	20	23	18	34	22	19	**23**
	Only if they get a loan or a grant	32	49	33	40	26	29	**35**
	=150 USD	37	25	42	25	50	49	**38**
	150 –300 USD	11	2	11	0	2	3	5
	300–500 USD	4	1	2	1	3	5	3
	500–1000 USD	0	0	0	0	0	0	0
	>1000 USD	0	0	0	0	0	0	0
Cost ratio of CBRWHS in relation to whole-house construction	<1%	1	0	2	0	1	1	1
	1–3%	3	1	4	2	4	5	3
	3–5%	43	10	16	10	30	34	24
	>5%	53	89	78	88	65	60	**72**
Maintenance costs per year	I do not know	89	98	94	88	81	83	**89**
	50 USD	0	0	0	0	0	3	1
	50–80 USD	10	2	4	7	10	9	7
	80–120 USD	1	0	1	5	9	4	3
	120–200 USD	0	0	0	0	0	0	0
	>200 USD	0	0	1	0	0	1	0
Cost efficiency of CBRWHS	Not at all	2	0	0	0	5	2	2
	Very low	0	0	0	0	0	0	0
	Low	1	3	4	3	1	1	2
	Moderate	65	56	78	69	59	65	**65**
	High	8	41	6	28	9	3	16
	Very high	24	0	12	0	26	29	15

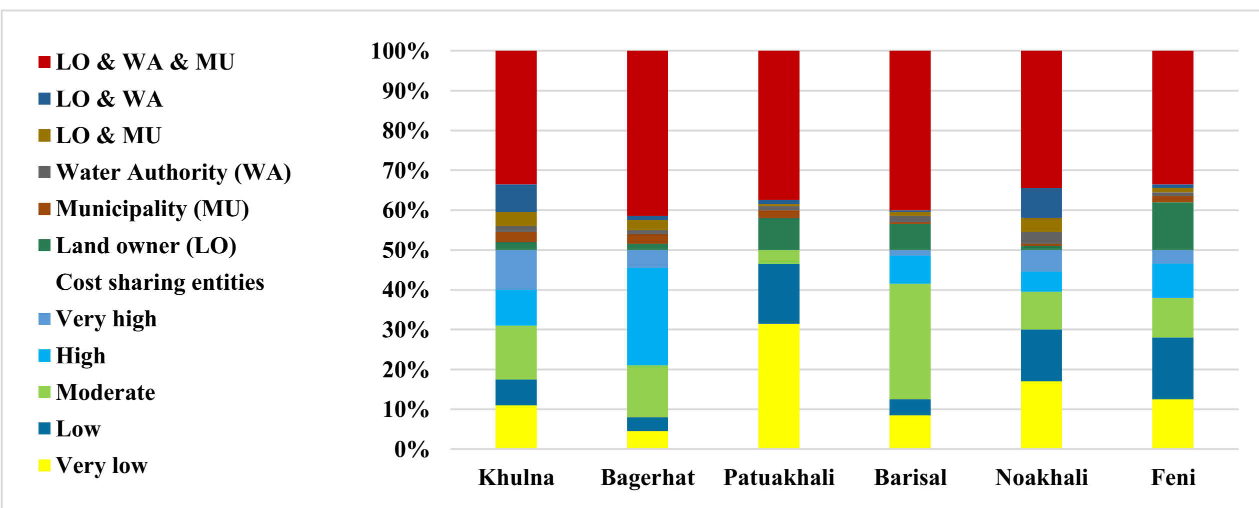

Fig. 26. Perception of coastal respondents regarding institution-based aspects of CBRWHS adoption.

assessed in this study by utilizing a dual approach - a bottom-up perspective (coastal respondents) and a top-down perspective (experts).

Residents across the six study cities expressed concern over the high salinity levels in their ponds and other water sources. Although many do not currently employ RWHS, a strong consensus exists on the potential benefits of such systems, particularly in Barisal and Bagerhat City. However, it is essential to note that a substantial proportion of respondents across different cities possess limited knowledge of RWHS or CBRWHS. Survey results highlighted the belief that harvested rainwater would provide a more valuable resource for domestic and drinking purposes than existing natural water sources. Despite heightened awareness of rainwater harvesting's importance, inadequate financial support, scarcity of technical resources, lack of training facilities, absence of suitable regulations, and ineffective monitoring and maintenance practices hinder the sustainability of RWHS. Experts identify the dispersion of knowledge and technical proficiency as the principal challenges to implementing CBRWHS in the studied areas.

The research utilized top-down and bottom-up approaches to establish residents' WTP for CBRWHS. While top-down results suggest an average installation cost of approximately $225 for individual household-based RWHS, the majority of respondents indicated a willingness to install RWHS at a cost of around $150. Economic constraints, however, led to many respondents expressing their inability to afford individual household-based RWHS, with a significant portion open to community-based RWHS. Field survey results indicated that lack of knowledge and economic challenges are primary barriers to the residents' willingness to pay for CBRWHS, with calls for governmental, municipal, and local affluent individuals' assistance to facilitate CBRWHS installation. However, experts stress that without technical proficiency regarding the installation, operation, and maintenance

Table 8
Perceived concerns and incentives to install and maintain RWHS (Unit:%).

Question/Criteria	Response options	Khulna	Bagerhat	Patuakhali	Barisal	Noakhali	Feni	All
Principal concerns regarding mandating the RWHS	Its water quality	50	0	15	20	21	90	**33**
	Its water quantity	40	20	23	15	14	60	29
	Its monetary facets	23	51	19	39	43	40	**36**
	Its technological attributes	30	41	45	41	21	38	**36**
	Its sphere of space occupancy	20	60	12	30	10	70	34
Principal technique or strategy to promote RWHS acceptability	Financial support (subsidy) by government	61	68	52	49	32	37	**50**
	Technical support by government	17	21	40	42	25	20	28
	Provision of loans at low interest	11	10	80	50	19	60	38
	Escalating water rates	20	0	0	0	50	0	12
	Obligating RWHS in new constructions	10	0	0	20	11	18	10
	Awareness raising /extension activities	80	10	0	20	80	19	35
Most efficient way of extension and increasing awareness to enhance RWHS acceptance	Education programs via public media	16	0	60	20	38	26	27
	Publication and distribution of instruction booklets and pamphlets	10	20	80	20	13	90	39
	Conducting educational workshops for improving technical skills	33	52	40	41	29	54	**42**
	Installation of a pilot RWH system in public areas	29	38	22	27	19	11	24
	Educating in schools	12	80	24	10	10	10	24
Providing inducements to construct and use RWHS	Allocating subsidy or cash assistance	33	37	23	41	35	18	31
	Showcasing successful examples of RWHS	30	0	0	14	10	10	11
	Ensuring that the installation of RWHS does not hinder access to municipal water	40	0	0	0	30	0	12
	Providing RWHS with operational and technical support services	20	33	18	18	20	35	24
	Ensuring the cost-effectiveness of RWHS	37	30	58	27	40	43	**39**
	Assuring environmental and water supply improvement	30	0	10	0	10	30	13

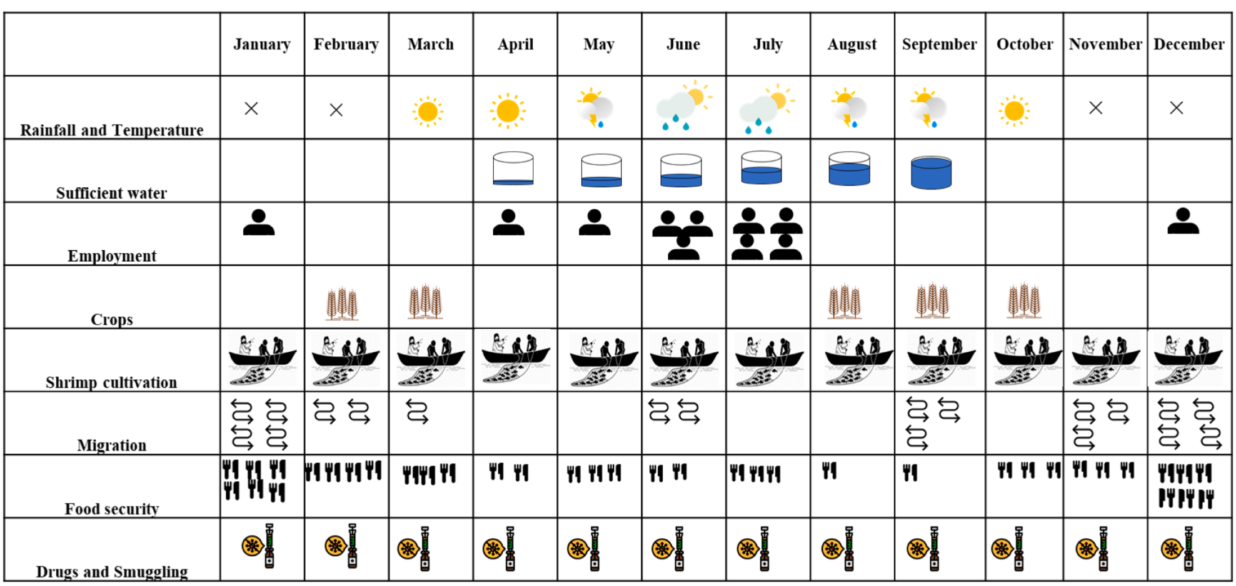

Fig. 27. Seasonal calendar (produced by participants and digitized by author).

processes, local community adoption of CBRWHS would be challenging. Both respondents and experts highlighted the need for cost-effective CBRWHS solutions to address the enduring freshwater crisis.

By formulating suitable policies, comprehensive planning and implementation, and proactive and thoughtful actions, rainwater harvesting could be endorsed as a sustainable development strategy that benefits water supply and management. Water resource development authorities and communities are strongly urged to promote and mandate the adoption of rainwater harvesting in coastal areas, taking cues from other pioneering nations. This study's findings can aid in assessing the practical applicability of CBRWHS in other coastal regions, thus saving time and resources in examining the perceptions of local residents and official experts. This research aspires to identify feasible solutions to tackle the severe water supply challenges in water-scarce coastal regions of Bangladesh and similar regions globally.

In terms of future research, exploring effective policy mechanisms and frameworks for supporting RWHS, examining the social, economic, and environmental impacts of RWHS, and undertaking detailed cost-benefit analyses are recommended. In addition, studying the impact of RWHS on gender dynamics and household labor could provide valuable insights into the broader societal implications of this technology. Moreover, designing and testing innovative and affordable RWHS designs, focusing on low-income communities, could be another potential research avenue. Finally, longitudinal studies that track the long-term sustainability and impact of RWHS in these regions would contribute significantly to the understanding and promotion of rainwater harvesting systems.

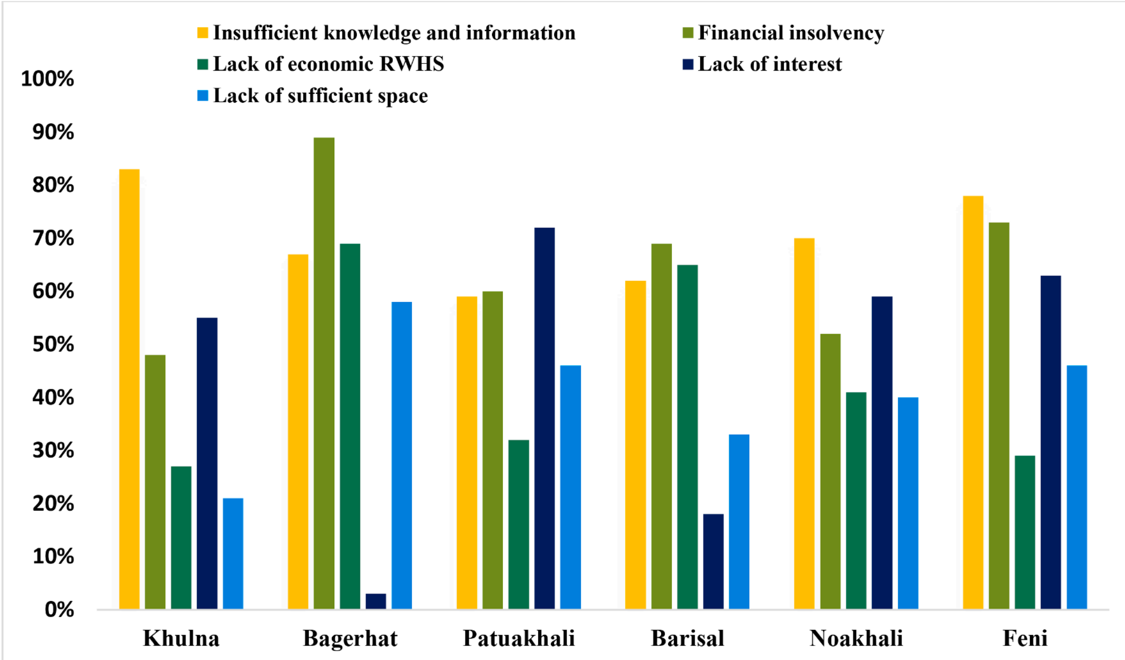

Fig. 28. Coastal public opinions of RWHS adoption constraints (produced by author).

CRediT authorship contribution statement

Mirza Md Tasnim Mukarram: Conceptualization, Project administration, Formal analysis, Data curation, Supervision, Resources, Software, Methodology, Investigation, Writing – original draft, Validation, Writing – review & editing. **Abdulla - Al Kafy:** Project administration, Formal analysis, Data curation, Supervision, Resources, Software, Methodology, Investigation, Writing – original draft, Validation, Writing – review & editing. **Mirza Md Tahsin Mukarram:** Formal analysis, Data curation, Supervision, Resources, Software, Methodology, Investigation, Writing – original draft, Validation, Writing – review & editing. **Quazi Umme Rukiya:** Formal analysis, Data curation, Supervision, Resources, Software, Methodology, Investigation, Writing – original draft, Validation, Writing – review & editing. **Abdulaziz I. Almulhim:** Methodology, Investigation, Data curation, Conceptualization, Writing – review & editing, Project administration. **Anutosh Das:** Formal analysis, Data curation, Supervision, Resources, Software, Methodology, Investigation, Writing – original draft, Validation, Writing – review & editing. **Md. Abdul Fattah:** Data curation, Supervision, Resources, Software, Methodology, Investigation, Writing – original draft, Validation, Writing – review & editing. **Muhammad Tauhidur Rahman:** Data curation, Supervision, Resources, Software, Methodology, Investigation, Validation, Writing – review & editing. **Md. Arif Chowdhury:** Formal analysis, Data curation, Software, Methodology, Investigation, Writing – original draft, Validation, Writing – review & editing.

Declaration of Competing Interest

The authors declared that they have no known competing financial interests or personal relationships that might seem to have influenced the work reported in this paper.

Data availability

Data will be made available on request.

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