COMPARISON OF WATER SUPPLY SYSTEMS SUSTAINABILITY IN PAIKGACHA MUNICIPALITY

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ABSTRACT

The coastal belt of Bangladesh is identified as a problematic area where it desperately needs safe drinking water. The situation is worsening more seriously because of frequent natural disasters. Various water supply systems (WSS) such as Deep Tubewell (DTW), Metered water (MW), Rain Water Harvesting (RWH), Reverse osmosis (RO), and Shallow Tubewell (STW) are being used in this region to address the drinking water shortage problem. The study area is Paikgacha Municipality of Khulna district. The primary objective of this research is to assess the sustainability of different WSSs based on three pillars: technical suitability, economic viability, and social acceptability. The socio-economic aspects data of the study area were gathered through the household survey using a structured questionnaire. In order to assess technical appropriateness,50 water samples were collected from different WSS in the study area to measure the selected water quality parameters (Chloride, pH, Iron, TDS, Turbidity, Electrical Conductivity, Arsenic, Manganese, Color, Total Coliform, and Fecal Coliform**)**. The water quality index (WQI) value was calculated through the weighted Arithmetic Water Quality Index method approach to determine the acceptability of water for drinking purposes. Primary data has been collected through questionnaire survey, focus group discussion (FGD), and key informant interview (KII). Secondary data was collected through various organizations (GO/NGO/INGO) and from various reports, research articles, and journal papers. The main outcome of this research is to evaluate the sustainability of different WSS and determine the sustainability point for different WSS and the level of sustainability on 3 predefined pillars for the respective WSS. From the three pillars, coastal dwellers of the study area will be able to find suitable and sustainable WSS according to their need to meet the drinking water demand. Another outcome of this study is to evaluate a technically suitable, economically feasible, and socially acceptable water supply system for the salinity-prone southwestern coastal region of Bangladesh. This study will also explore different strategies of metered water supply systems in the study area. Revenue generation potential from metered water pricing could emerge which can contribute to the national economy. This research will provide guidelines to the residents of the study area to find a suitable and sustainable WSS according to their socioeconomic needs. The findings of the study will also be useful for different organizations like governmental, non-governmental, and private as well as donor organizations to fix and set out the new criteria for operation-maintenance and implementation of sustainable drinking WSS for the people of southwestern coastal areas.

Keywords: *Urban, Rural, Water Supply System, RO, RWH, Water Quality Index*

1. INTRODUCTION

Bangladesh, a densely populated country, achieved a major breakthrough in the 1990s by providing shallow tube wells for groundwater extraction to ensure drinking water for rural people (Ahmed and Rahman, 2000). The idea of using shallow tube wells for safe drinking water across the country has been thwarted due to severe arsenic contamination of groundwater mostly in the upper aquifers of Bangladesh (Shafiquzzaman et. al., 2011). Lack of safe drinking water is a growing problem for the coastal regions. The coastal belt of Bangladesh is recognized as a more problematic area to supply ample drinking water to the community as the groundwater sources contain high salinity along with other contamination problems (Ahmed et. al. 2014; Bari and Selim, 2020). This makes water supply to coastal communities difficult compared to other parts of the country. The report of WHO shows that the underground water of the Southwestern region of Bangladesh (Satkhira, Khulna, and Bagerhat) is not suitable for human consumption due to high salinity and arsenic contamination (WHO, 2004). This report is valid for upper aquifers in the whole region. There are some pocket aquifers also present with fresh water (Bari et. al. 2022). Specific areas in the coastal belt have a severe scarcity of drinking water sources due to multiple contamination problems (Bari and Selim, 2020).

Climate change worsens the situation by increasing temperature, erratic rainfall, sea level rise, salinity intrusion and frequent extreme events like cyclones, storm surges, floods, river bank erosion, etc. National water and sanitation coverage in these areas is still much lower than the basic minimum level. The Government's vision plan prioritizes interventions to ensure access to safe drinking water, sanitation and good hygiene practices for all. The GOB's post-2015 development agenda (2016-2030) is under the theme of safe and sustainable sanitation, hygiene and safe water for all". The development of different low-cost water supply systems has become the necessary alternative to improve the water supply situation in the coastal areas. Several different types of water supply systems presently prevail in the coastal area including the selected study area. The main sources of water in coastal areas are rivers, reservoirs, lakes, canals, ponds, and groundwater of shallow and deep aquifers. Surface and groundwater sources are available and abundant in coastal areas, and the water quality of these sources is the worst which has become a major obstacle to the development of safe and effective Water Supply System (WSS) (Bari et al. 2022).

PSF(Pondsand Filter) has been supplying drinking water in the area despite limitations. The water quantity and quality of PSF is highly dependent on the water quality of the pond concerned, PSF is not accurate for ponds that have high salinity, potassium and chloride (Mondal and Bari, 2023). Rainwater harvesting is also preferred for WSS in coastal communities. The average annual rainfall in Bangladesh is 2410mm, of which 75% occurs between May and September. Rainwater harvesting can effectively provide potable drinking water to people in arsenic-contaminated areas. Excess rainwater can be collected and stored during the rainy season for use during the dry season (Imteaz, 2011, ABCB 2016). Water metering is one of the most efficient strategies for improving the management of water distribution systems, mainly in urban areas, which has the potential to add revenue to the national economy. External factors including the effects of climate change, drought and population growth are compounded by internal factors including illegal metered connections, leakage in pipelines, poor quality supply, irregular supply etc. which create obstacles to sustainable water supply systems. Their sustainability is to be compared in a very simple manner.

The South west coastal region of Bangladesh is facing a serious crisis due to saline water intrusion on one hand and arsenic contamination in groundwater on the other hand where PSF has been installed as an alternative water supply system (Harun et al., 2012). About 81,000 ponds in and around coastal areas with low salinity water are considered as sources of low-cost water supply (Ahmed M.F.,1996). About 50 million people in Bangladesh are currently at risk of chronic consumption of high concentrations. The main sources of water in coastal areas are rivers, reservoirs, lakes, canals, ponds and groundwater of shallow and deep aquifers. In some areas of the coastal region of Bangladesh, neither shallow tube well nor Deep tube well is successful, even the depth between 200m-350m depth. Water metering is one of the most efficient strategies for improving the management of water distribution systems, mainly in urban areas; Alternative water supply systems are working well in some areas and not working properly in other areas. Evaluation of alternative water supply systems from both technical and economic perspectives is essential to identify causes of non-performance, develop Comparative data and better understand alternatives. Although well-planned studies focusing on water supply systems based on specific technologies and specific issues such as salinity, arsenic, and manganese have been conducted; nevertheless there is few comprehensive study to identify technically viable, economically feasible and socially acceptable drinking water supply systems for specific study area under the coastal region in Khulna (Mondal, 2023). Hopefully, this research will fill this knowledge gap. Selected number of different existing water supply systems (WSS) namely: PSF, shallow tube well, deep tube well, rainwater storage harvesting and water treatment by RO will be considered in this research. An attempt is made to compare the sustainability of the WSS considering three pillars namely technological, social and economic aspects.

2. METHODOLOGY

Universal access to water and sanitation as well as long-term management of these resources are recommended in SDG 6. By 2030, SDG 6 aims to provide universal and equitable access to safe and affordable drinking water for all. This study is for safe and sustainable WSS of the study area. The study was done closely with the objectives. This study used quantitative and qualitative data equally. Data were collected directly from individuals at the study site using questionnaire survey methods. Household questionnaire survey, focus group discussion (FGD), key informant interview (KII), water sample collection and testing were carried out to get a better idea and knowledge about their current water security situation.

2.1. Study Area

Paikgacha Municipality of Bangladesh is located in the southwest coastal region of Bangladesh which has been selected as the study area. Since the Paikgacha Municipality is located close to the Bay of Bengal as a result severe saline water intrusion has become a very common phenomenon here. The problem of drinking water is severely acute and many options have already been tried for drinking WSS in this area was selected as study are is shown in Figure 1.

Figure 1: Map of the study area

Paikgacha Upazila is bounded on the north by Tala Upazila of Satkhira district, on the east by Dakop and Batiaghata Upazila of Khulna District, on the south by Koyra Upazila of Khulna District and on the west by Asashuni Upazila of Satkhira District. Paikgacha Upazila is situated between 22º28' and 22º43' north-south latitudes and 89º14' and 89º28' east-west longitudes. The total area of the Paikgacha Upazila is about 383.87 km^2. Paikgacha Upazila is divided into Paikgacha Municipality and ten Union councils. The area of the Paikgacha municipal town is 2.52 km^2 which is subdivided into 9 wards and 5 mahallas. The municipality has a population of 16,017 with male 51.2% and female 48.8%; population density of 2,896/ km^2.

2.2. Sources of Data Collection

The data was collected from both primary and secondary sources. Primary data were collected through face-to-face structured household questionnaire surveys, focus group discussions, key informant interviews and water sample collection and testing. Relevant research papers, journals, various reports and documents from the Department of Public Health Engineering (DPHE), Paikgacha Municipality were secondary sources of data.

2.3. Water Sample Collection and Testing

Water samples were collected from the study area by random selection of WSS to check the water quality status in the laboratory. Appropriate sampling procedures were followed to ensure accuracy and representativeness. A total 50 drinking water samples were collected from different sources from the study area. Two samples from Deep Tube Well (DTW), 10 from Metered Water (MW), 1 from Pondsand Filter (PSF), 7 from Reverse Osmosis (RO), 10 from Rain Water Harvesting (RWH), 10 from Shallow Tube Well (STW) and 10 from Surface Water (SW). Laboratory analysis for selected water quality measurements like Salinity as Chloride, pH, Iron, TDS, Turbidity, Conductivity, Arsenic, Manganese, Color, Total Coliform, and Fecal Coliform has been carried out in the Environmental Engineering Laboratory of the Department of Civil Engineering of Khulna University of Engineering & Technology.

3. RESULTS AND DISCUSSION

3.1. Information Regarding Drinking Water Sources

From the field survey results, it was observed that a maximum of 58% of the population in the study area relies on Reverse Osmosis (RO) as shown in Figure 2. Usually small family size to medium community size RO filters are in operation in the area (Rabbani & Bari 2021). 24% of the population uses rainwater but this water was stored. Storage of rainwater is identified as a problematic issue due to the high cost of large storage tanks. Nowadays Reverse Osmosis technology (58%) is also gaining popularity for its good quality water and Some vendors are commercially supplying RO water, indicating economic opportunities. 16% of people use metered water indicates a portion of the population has access to this WSS option. About 2% of the people in the region use water from Deep Tube Wells for drinking purposes and not all geographical locations of the municipality have been successful in installing Deep Tube Wells due to salinity intrusion. Most people use Pond Sand Filters for cooking purposes and Shallow Tube Wells are used for domestic purposes. Some people in this region use Surface Water (SW) from ponds for bathing, washing clothes, and sometimes for household purposes.Some vendors are commercially supplying RO water, indicating economic opportunities.

3.2. Distance of Water Sources from Household

From the site visit, it was observed that the role of females was more prominent than males in fetching individual household’s drinking water. This observation reflects gender dynamics in water management, and understanding these roles is essential for developing targeted and inclusive water

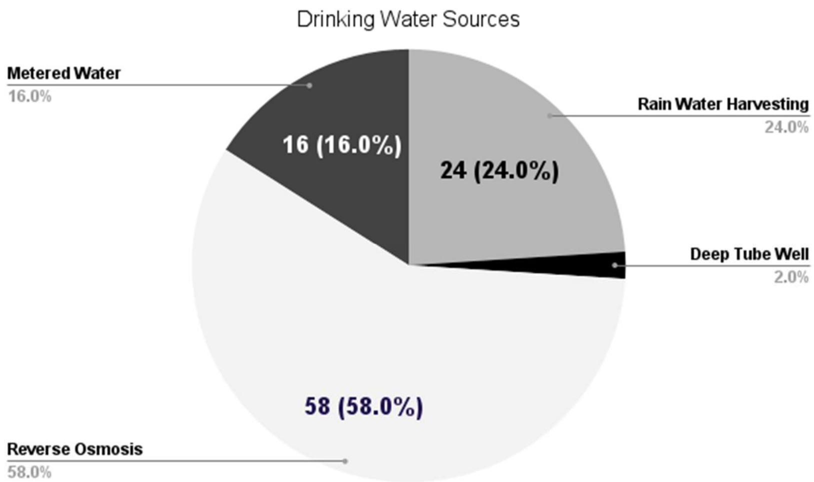

Figure 2: Drinking water Sources of the study area

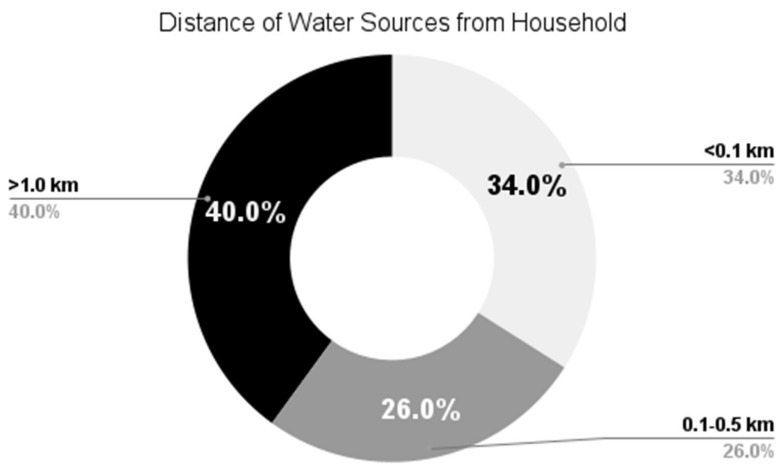

Figure 3: Distance of water sources from household

security solutions. It was also found that about 34% of respondents collect water from the shortest distance (<0.1 km) indicating that a significant portion of the population has relatively convenient access to water sources. However, The majority (40%) of respondents collect water from the largest distance, which is more than 1.0 km (Figure 3). Approximately 26% of people travel to distances ranging from 0.1 km to 0.5 km for water collection. Overall results indicate that residents in the study area face water insecurity due to the remoteness of a water source. As a result, the residents in the study site need to boost their water security status.

3.3. Technological Aspects of Different WSS

Installation and maintenance cost of different WSS is shown in Figure 4 which is very similar to Mondal B (2022). Among all WSS, MW is the most expensive technology with an annual maintenance cost of around 40,000 BDT. RO, SW, and RWH have minimum annual maintenance, costs, which are 25,000, 10,000 and 1,000 BDT, respectively. The storage tanks of RWH need to be cleaned before monsoon to start storing water for drinking purposes. RWH storage tank installation cost may vary due to storage tank capacity. Long-term storage and management of rainwater is difficult. STW and DTW are simple technologies and can be installed by 25000 and 50000 BDT, respectively. Replacement parts and accessories for STW and DTW are generally accessible in the local market of the study area, and they are easy to repair at low cost. However, despite being a simple technology, DTW has not been successful in the study area. The PSF works with a pond that filters the pond water and the scarcity of surface water during the dry season creates problems for the SW and PSF. SW installation is around 40000 BDT whereas PSF installation is twice that of SW. Acceptance of RO, and RWH is always high as they can supply water throughout the year through the current water deficit during the dry season. However, due to pathogenic pollution, misuse and inadequate maintenance, rainwater harvesting for long periods is challenging. Salt levels in water in coastal areas are so high and filtering this water through membrane filters of RO plants reduces the lifespan of RO technology. Repair equipment and technicians are insufficient to operate MW and RO plants and this was indicated from the point of view of local people. A metered water system delivers water through pipelines and can misuse water leaking into pipelines.

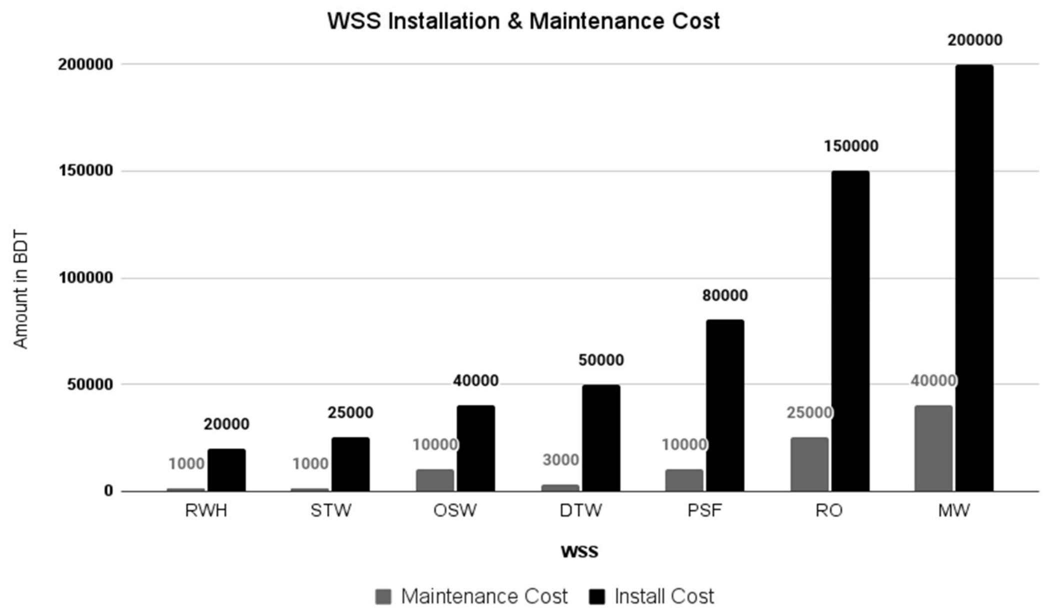

Figure 4: WSS Installation & Maintenance Cost in the Study Area

Illegal connections without meters or connections with non-functioning meters can hamper the revenue generation activities of metered water supply systems. PSF filters SW and people use water from both SW and PSF for cooking purposes. Stormwater intrusion, poorly protected dams, and the short distance of the pond to latrines can impair the water quality of PSF and SW. Easy access, water quality, management, water availability, and fee collection all influence consumer acceptance of drinking water technology.

3.4. Respondent's Perception of Drinking Water Services

The respondent's perceptions of safe drinking services in their respective communities are indicated in Table 1. Roughly 40% of individuals express dissatisfaction with the distance of their water source. because it is a relatively long distance from their home. Around 70% of respondents are satisfied with the current water quality supplied by various Water Supply Systems (WSS) in their community. Maximum people cited that there is a high percentage of salt and iron in their drinking water and some told about the arsenic problem but nobody had any idea about manganese in their drinking water. The survey also reveals that only 20% of people received financial support from GO/NGO or others for WSS. 62% of respondents reported not using water purification methods (such as filtering, boiling, filtering by cloth, etc.) after water collection. According to the monthly cost for water versus water quality, 30% of respondents expressed dissatisfaction. Almost 16% of people stated that their

WSS has an impact from disasters. 12% of the people disclosed that they are not severely but sometimes influenced by waterborne diseases.

Table 1: Respondent's perception of Drinking Water services as social values

Perception Variable	Satisfactory (%)	Unsatisfactory (%)	Ranking
Distance of Water Source	60	40	4
Water Quality	40	60	5
Financial Support from GO/NGO or others for WSS	20	80	7
Water Purification after Collection	38	62	6
Monthly Water Cost Vs. Water Quality	70	30	3
Impact of Disaster on WSS	84	16	2
Severe Influence of Waterborne Diseases	88	12	1

3.5. Water Quality of Different WSS & Water Sample Test Results

A total 50 water samples (2 DTW, 10 MW, 1 PSF, 7 RO, 10 RWH, 10 STW, and 10 SW) were obtained from the study area's WSS to perform water quality analysis. To highlight the water quality status in the site of study, various selected tests (Salinity as Chloride, pH, Iron, TDS, Turbidity, Conductivity, Arsenic, Manganese, Color, Total Coliform, and Fecal Coliform) were performed on collected water samples. Average WQ Values ± Standard Deviation (SD) of selected WQ parameters for different WSS are shown in Table 2. The Chloride of SW and STW are higher than the Bangladeshi Standard value whereas RWH and DTW have lower than the standard range. Iron level is satisfactory for all the WSS except STW.

Table 2: Water Quality of Different Samples collected from WSS

WSS	Cl^- mg/l	pH	Iron, mg/l	TDS, mg/l	Turbi-dity, NTU	Con. mS	As mg/l,	Mn mg/l,	Color, PtCo	TC[a]	FC[a]
DTW	99.84 (72.)	7.2 (0.14)	0.04 (0)	444.5 (77.1)	2.02 (1.6)	0.77 (0.15)	0.1 (0)	0	29.5 (26.2)	18.5 (26)	5 (7.1)
MW	471.07 (80.4)	7.4 (0.10)	0.02 (0.01)	781.1 (70.3)	0.72 (0.3)	1.36 (0.06)	0.06 (0.03)	0.16 (0.1)	3.4 (2.4)	7.1 (4.6)	0.5(1)
PSF	978	7.7	0	855	1.55	1.45	0	0	13	102	1
RO	135.6 (45.9)	6.4 (0.3)	0.06 (0.05)	133 (113)	0.87 (0.1)	0.23 (0.19)	0.01 (0.01)	0	1 (2.7)	5.71 (7.1)	1.14 (3.02)
RWH	22.41 (13.2)	8.2 (0.4)	0	45.8 (38.9)	0.92 (0.2)	0.09 (0.07)	0	0	2 (2.1)	40.4 (30.3)	15.4 (29.8)
STW	2080 (1042)	6.6 (0.2)	3.51 (1.7)	330 (313)	75 (33)	3 (1)	0	0.5 (0.46)	243 (245)	17.5 (34.8)	11.7 (35.3)
SW	903.02 (221)	7.6 (0.2)	0	586.2 (343)	97.51 (120)	1	0	0	80.6 (62.3)	241.6 (196)	88.2 (154)
ECR	600	6.5-8.5	0.3-1.0	1000	5		0.05	0.4	15	0	0

ECR = BDS 2023; () = Standard Deviation; Cl^- = Chloride; Con. =Conductivity; As = Arsenic; Mn = Manganese; [a]Average value; Unit of TC & FC no/100ml.

The TDS value is highest in PSF and MW and lowest in RWH. Turbidity concentrations were within the range of standard levels for all WSSs, except STW and SW. A low level of arsenic was detected in the RO, MW, and DTW whereas, no arsenic was found in the RWH, STW, PSF, and SW samples.

The water sources in the study area are more safe in term of arsenic contamination than other sever problematic area in Bangaldesh (Shafiquzzaman et. al 2022; Shafiquzzaman et. al 2023). In the RO samples, arsenic has been found within the limit. The maximum level of arsenic is found in MW samples. The result of manganese shows that there is no manganese except STW and MW. The color value is lowest in RO (1) and highest in STW (242.6). The RO(5.71) contains the lowest number of TC and SW(241.6) contains the highest number of TC. The FC value is lowest in PSF(1) and highest in SW(88.2).

3.6. Water Quality Index (WQI)

To analyze the water quality in the laboratory, weighted arithmetic water quality index method is used for Water Quality Index (WQI) value; thus, to assess suitability of water for drinking purposes. The permissible WQI value will be considered as <50=excellent; 50- 100 good water; 101-200 poor water; 201-300 very poor water, >300 water unsuitable for drinking. In this method, water quality rating scale, relative weight and overall WQI will be calculated by the following formula (Bari et. al. 2022):

$$q_i = (c_i/s_i) * 100 \quad (1)$$

Where, q_i, c_i, s_i indicated respectively quality rating scale, concentration of i parameter and standard value of i parameter.
Relative weight was calculated by : $w_i = 1/s_i$
Where, the standard value of i parameter is inversely proportional to relative weight. Overall WQI was calculated according to the following expression:

$$WQI = \frac{\sum q_i w_i}{\sum w_i} \quad (2)$$

Table 3: Average WQ Values of Different WSS

WSS	WQI	Water Quality	Sustainability Rank
DTW	190	Poor	7
MW	55	Good	3
PSF	135	Poor	5
RO	11	Excellent	2
RWH	3	Excellent	1
STW	171	Poor	6
SW	103	Poor	4

Government and non-government organizations are still working together to alleviate the suffering of coastal residents due to lack of safe drinking water. They are trying to develop an easy way to provide access to water supply for all user levels and authorities may prefer to follow the assessed sustainability mandate of WSS for improvement. This is something that the government as well as other organizations should pay more attention to this issue.

3.7. Comparison of WSS considering three pillars

A comparison of WSS considering three pillars namely technological, social, and economic aspects was performed. From Table 3 we explore the technological suitability through water quality analysis. Social acceptability is calculated based on various social viewpoints of these technologies presented in Table 1 and Figure 4. Economic viability is assessed through the installation and maintenance costs of Water Supply Systems (WSS) as shown in Figure 4. RWH is identified as the best-performing water supply system in the study area based on the comprehensive comparison (Table 4). After RWH, RO, MW, STW, PSF, SW, and DTW, respectively were ranked in descending order as shown in Table 4. In descending order, it can be presented as RWH>RO>MW>STW>DTW>PSF> SW.

This comprehensive comparison provides valuable insights for decision-makers, planners, and communities in selecting and maintaining effective and sustainable water supply systems tailored to the needs of the study area.

Table 4. Comparison of WSS using three pillars of technological, social, and economic aspects

Three pillars	DTW	MW	PSF	RO	RWH	STW	SW
Technological	7	3	5	2	1	6	4
Social	4	3	5	1	2	6	7
Economic	4	7	5	6	1	2	3
Sustainability Rank	5 (15)	3 (13)	6* (15)	2 (9)	1 (4)	4* (14)	7 (14)

*Considering the TC & FC value according to Table 2.

4. CONCLUSIONS

Coastal residents use different types of WSS to adapt to natural processes and daily needs. In the study area, several water supply systems are being tried to overcome the problem of safe drinking water. Moreover, the study location is frequently affected by various natural calamities throughout the year, resulting in severe disruption of the drinking water supply. Also, not every WSS is effective all year round. There is little variation in comfort with drinking water supply options related to water quality among different income levels. Technical compatibility, as well as maintenance and user acceptance, determine the long-term sustainability of various WSSs. RWH and RO are the most suitable and STW is the least due to technical aspects. In contrast, STW is user-friendly and best suited from a social context perspective. However, the WQ value of RO is good but it is expensive, so people cannot install this WSS easily. RWH and STW are economically viable WSS for the people of the study area. On a short basis, STW water can be used for domestic activities and even drinking, yet not continuously. RWH, MW system can help in reducing the problem of drinking water from the study area on a large scale.

Finally the specific conclusions are:

- A maximum of people of 58% depend on Reverse Osmosis in the study area.
- It was observed that the role of females was more than males in fetching individual household's drinking water.
- It was also found that about 34% of respondents collect water from the shortest distance & it is less than 0.1 km.
- The Rain water harvesting and reverse osmosis systems are the most suitable in the context of the study area. In contrast, STW is user-friendly and best suited from a social perspective for different usages other than drinking.

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