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A Comparative Study between Managed Aquifer Recharge and Other Community Water Supply Options in Coastal Bangladesh

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ABSTRACT

The acute scarcity of safe water exists in disaster-prone coastal Bangladesh due to the occurrences of brackish or saline and arsenic contaminated groundwater, the salinization of freshwater ponds by inundation during storm surges, and brackish water aquaculture. Millions of people living there mainly depend on pond water and rainwater harvesting system and face severe difficulties to collect freshwater, particularly during the dry season. Therefore, various community water supply technologies, e.g., RO, SIDKO, RPWS, SkyHydrants etc. have been established to meet their daily needs, though the majority of these technologies fall short of the value of time and effort of water collection and sometimes fail to supply water of desired quality. Managed Aquifer Recharge (MAR) technique, also a community water supply system, was designed to provide safe water by creating underground storage of freshwater where ambient groundwater salinity is reduced by infiltrating rooftop or pond water through wells. Understanding the need to sort out the best water supply option, a comparative study has been conducted between MAR and other water supply technologies, and among all of them the MAR has been demonstrated as a low cost, reliable, sustainable, and durable option for providing safe drinking water to the community round the year.

Introduction

The coastal communities of southwestern Bangladesh, particularly along the northern fringe of the Sundarban mangrove forest in Khulna, Satkhira and Bagerhat districts, have been confronting critical shortages of freshwater for many years (Karim and Mimura, 2008). The major reasons behind this misery are naturally occurring salinity and arsenic in groundwater (Sultana et al., 2015; Ahmed et al., 2004), gradual salinization of freshwater ponds by seawater inundation caused by seasonal storm surges (Barker, 2013; Mallick et al., 2011) and widespread man-made transformation of natural land use by brackish-water aquaculture (shrimp and crab) (Ahmed et al., 2009). Households mainly depend on pond water, rainwater harvesting (RWH), and pond sand filters (PSF) for drinking and cooking purposes as the number of shallow-water tube wells are few. However, all are vulnerable to pathogens and reliant on rain which is unevenly distributed annually. Additionally, a major portion of these areas is incompatible for deep tube well development (Hasan, 2012). Therefore, the local government, NGOs and some private funded agencies are engaged to recuperate from this situation. Some community water supply technologies, including Reverse Osmosis (RO), Arsenic Iron Removal Plant (AIRP) - SIDKO, Rural Pipe Water Supply (RPWS), SkyHydrant have been established, and they are being operated to supply freshwater to the community. However, water sourcing patterns, households' preference to water supply options and their economic feasibility suggest that a combination of household and community-based options could be suitable for year-round water supply particularly for drinking purposes.

An action research program, funded by UNICEF, Bangladesh in collaboration with the Department of Public Health Engineering (DPHE), the Department of Geology, University of Dhaka, Bangladesh and Acacia Water, Netherlands, was initiated in 2010 to test various designs of Managed Aquifer Recharge (MAR) system in coastal Bangladesh for improving groundwater quality and for acquiring knowledge on low cost construction and maintenance, operational methods using locally available materials (Hasan et al., 2018; Barker et al., 2016; Ahmed et al., 2015; Sultana et al., 2015). Initially, the MAR system has been constructed and operated at

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20 sites in three coastal districts of Bangladesh since 2012 to evaluate its performance and applicability. Their promising results led to implement additional 75 sites in 2015 as an alternate water supply technology to expand the access to safe drinking water to the coastal communities (Nawrin et al., 2016; Ahmed et al., 2015). However, these MAR schemes comprised of filtration unit, i.e., double chambered graded sand filtration tank, infiltration unit, i.e., four to six large diameter (12- to22-inch) infiltration wells filled with sorted gravel and recovery unit, i.e., a 2-inch diameter well fitted with hand pump. However, the optimum infiltration rate was hardly achieved. Moreover, larger diameter infiltration wells and double chambered graded sand filtration tankmade the construction and maintenance comparatively expensive (Ahmed et al., 2020; Nawrin et al., 2016). In addition, the low infiltration rate took one to two monsoon seasons to make groundwater sufficiently fresh in the shallow aquifer for potable uses. Hence, there was a need to improvise the design for enhancing infiltration rates with reduced costs in order to get a better recovery of fresh and safe groundwater and a modified MAR scheme has been constructed and tested at KDP site in Khashiar Danga village, Mongla, Bagerhat for optimum benefit (Nawrin et al., 2016).

Since both existing and modified MAR have already been proven as low cost, safe, year-round water supply technology in coastal Bangladesh (Ahmed et al., 2020; Hasan et al., 2018; Barker et al., 2016; Nawrin et al., 2016; Sultana et al., 2015), it creates an opportunity to study the competency of the MAR system (in this paper the modified MAR system) over the other water supply options in the study area. Keeping in mind the necessity to rank the community water supply technologies and to identify the best water supply option for the disaster-prone coastal communities in Bangladesh, a comparative approach has been adopted in this paper. First, each of these technologies is briefly described and then the analysis of collected data about their cost, accessibility, performance, maintenance, and water quality both on source and supply are presented in a systematic manner from which conclusions are drawn. This comparative study can help to enhance local knowledge in the context of water supply technologies, which is significant for fresh and safe water supply planning and management in the saline-prone coastal areas of Bangladesh. The distribution of available community water supply technologies and the modified MAR design "MAR-KDP" site are shown in Figure 1.

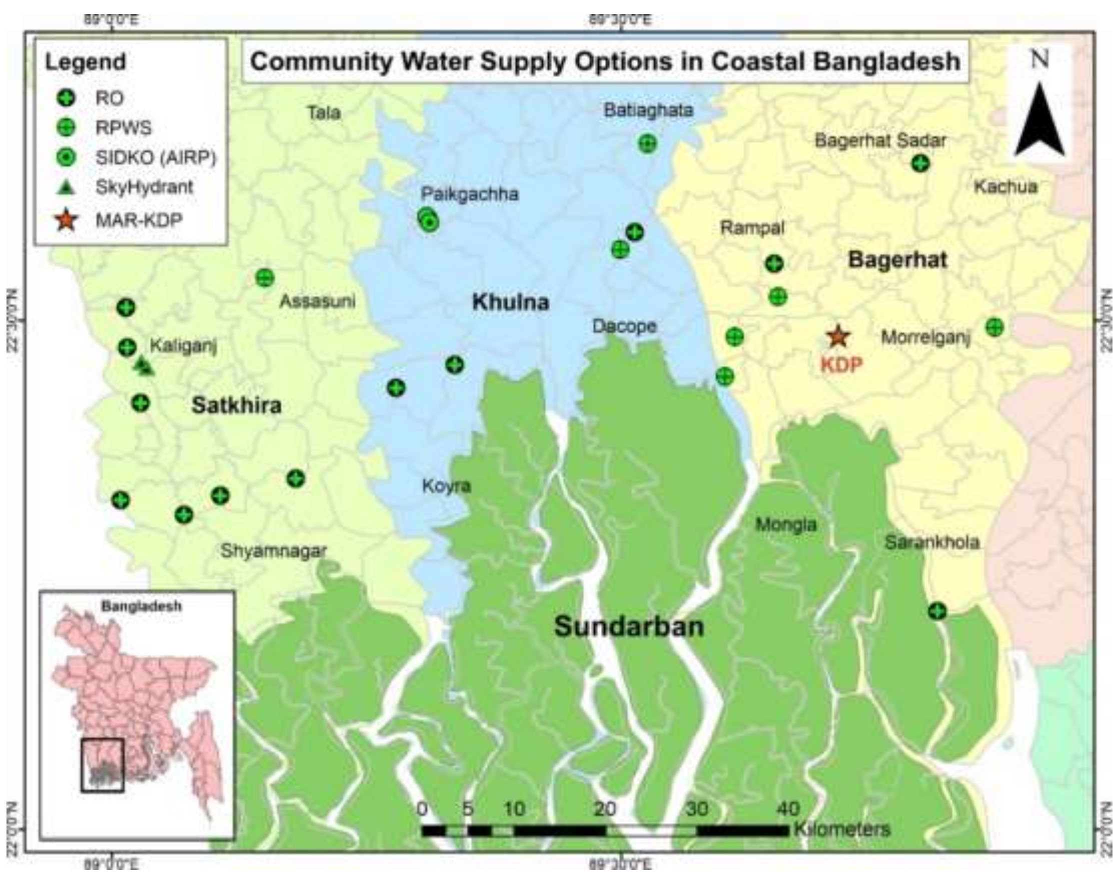

Figure 1: Location of MAR-KDP site and other available community water supply technologies in three coastal districts of Bangladesh

Managed Aquifer Recharge (MAR) System

MAR is one of the significant adaptation opportunities for developing countries seeking to minimize vulnerability to climate change and hydrological variability (IGRAC, 2016). The artificial recharge of groundwater can be achieved by infiltrating fresh and treated surface water in aquifers and subsequent recovery from wells (Bouwer, 2002), which is technically considered feasible and climate resilient alternatives for storing surplus monsoon run off in the regions of freshwater shortage (CGWB, 2000). Aquifer Storage Transfer and Recovery (ASTR) system is one of the MAR technologies, where either rooftop rain and/or filtered pond water are infiltrated into the shallow brackish aquifer during wet season (Sultana et al., 2015; Maliva and Missimer, 2010; Pyne, 2005). MAR schemes in Bangladesh are constructed mainly using local materials, which significantly reduces the construction and maintenance costs and provides a relatively low-cost option of fresh water supply for the coastal saline areas (Ahmed et al., 2020; Nawrin et al., 2016; Sultana et al., 2015). Several previous investigations on the detailed design, construction, and performance of implemented MAR system in the southwestern coastal areas of Bangladesh have been undertaken (Ahmed et al., 2020; Hasan et al., 2018; Barker et al., 2016; Nawrin et al., 2016; Sultana et al., 2015; Sultana et al., 2014; Monim, 2014; Hossain, 2014; Imranuzzaman, 2012). Figure 2 shows the modified and optimized design of the MAR system for enhanced infiltration rate at a comparatively low cost, which comprises three operating units for filtration, infiltration, and abstraction (Figure 2a) and source water pond (Figure 2b) at KDP (Khashiar Danga Pond) site in Mongla, Bagerhat district (Nawrin et al., 2016). In this optimized MAR design, an abandoned pond sand filter (PSF) has been modified and used as a filtration unit to remove source water turbidity which incurs negligible cost. Four 4-inch diameter empty recharge wells placed below a small 6x6 ft^2 recharge pit for the direct infiltration of treated water into the underground which significantly enhance infiltration rate. A scheme consisting of total nine observation wells in and around has been constructed in order to monitor water level and water quality. After one or two monsoon seasons of infiltration when the salinity of ambient groundwater reduced to drinkable limit, a number 6 hand pump has been installed fitted with a flow meter for abstracting groundwater (Figure 2a).

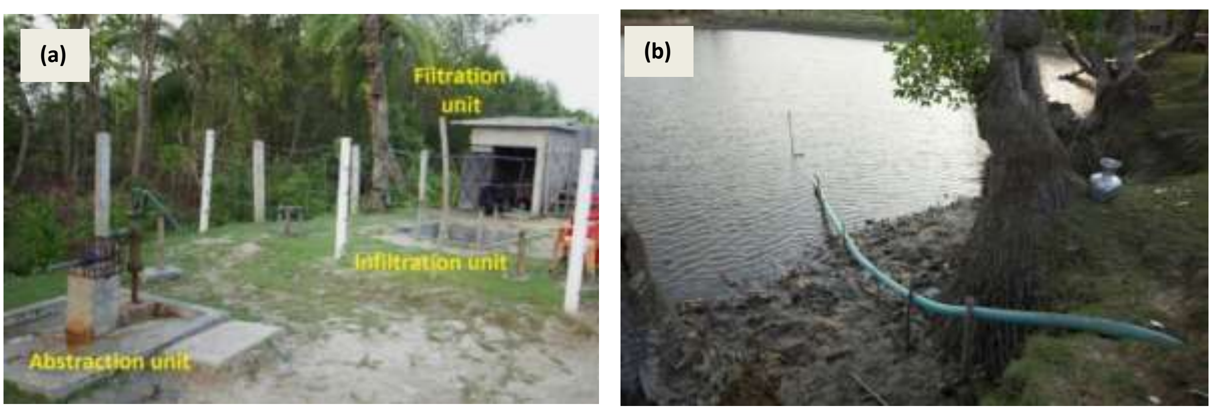

Figure 2: (a) MAR system showing filtration unit, infiltration unit and abstraction unit and (b) source water pond at KDP site in Mongla, Bagerhat district of Bangladesh

Other Water Supply Technologies

Reverse Osmosis (RO) is a water purification technology capable of removing up to 99% of the dissolved salts (ions), particles, colloids, organics and bacteria from the source water (Puretec, 2012). In the process of RO, water from a pressurized saline solution is separated from the dissolved salts by flowing through a water-permeable membrane, which is very effective in desalination or treating brackish surface and groundwater for both large and small flows applications (Khanzada et al., 2017). Fourteen (14) RO plants have been found operational in three coastal districts (Figure 3a).

Arsenic Iron Removal Plant (AIRP)–SIDKO removes arsenic and iron from groundwater through the sequences of oxidation, adsorption, and filtration processes (Chakraborty et al., 2016). Four (4) community level AIR plants, known as SIDKO in Bangladesh, are found operational (Figure 3b).

Rural Pipe Water Supply (RPWS) is an extensive supply of either pond water treated by sand filtration or groundwater direct from the deep tube well via a systematic pipe network. In the disaster-prone areas of Bangladesh, RPWS system tends to reduce sufferings of coastal communities by providing fresh water where either large pond reservoirs are available, or the aquifers are suitable for deep tube well installation. Eight (8) RPWS systems have been found in three districts of the coastal zone (Figure 3c).

Figure 3: (a) RO, (b) SIDKO (AIRP), (c) RPWS, and (d) SkyHydrant plants in three coastal districts of Bangladesh

SkyHydrant, which is one of the recent technologies in coastal Bangladesh, can remove pathogens and turbidity from both surface and groundwater sources. It is a low pressure, high volume, ultra-filtration unit. Raw water flows along the length of the hollow fibers before being forced through the walls of the fiber to produce a filtrate free of suspended solids. The filtrate flow rate is controlled manually (Skyhydrant Specification Sheet). Two SkyHydrant have been installed in Satkhira District (Figure 3d).

Materials and Methods

To complete a comparative investigation among the water supply options, a questionnaire survey (no. of samples, n=28) on four technological options was conducted to collect a number of information from each technology, including the location (GPS), the date of commission, installation agency, the cost of installation, capacity (L/day), the source of water, distribution type, the number of households covered, operational status, management authority, payment information, payment system, and community contribution and acceptance. The information about the source water quality (n=16) and supply water quality (n=18), e.g., the presence of salinity, arsenic, iron, bacteria, and smell were tested at the field sites. 26 samples of raw (source) water and 28 samples of treated (supply) water were also collected in 500 ml size plastic bottles for chemical analysis for some index water quality parameters. Note that samples of source water from two RPWS sites were not possible to collect as there was no water collection option from the well head. The samples were analyzed in the Geochemistry Laboratory of the Department of Geology, University of Dhaka for anions, i.e., Chloride (Cl^-) and Bicarbonate (HCO_3^-) and cation, i.e., Sodium (Na^+) and two trace elements, Arsenic (As) and Iron (Fe). At first, a 0.45µm membrane filter was used to remove suspended solids and colloidal substances from the samples. Un-acidified samples were analyzed for anions, Cl^- and HCO_3^-, by titration method and the concentration of cations, i.e., Na+, Fe (total) and As, were analyzed by Atomic Absorption Spectrometer (AAS) after acidifying the samples using ultra-pure nitric acid (HNO3) to lower the pH to slow down chemical and biological processes and to act as preservatives. The Electric Conductivity (EC) and pH of collected samples were also measured by using the portable EC meter (HANNA, model DIST HI 198300/4) and portable waterproof pH/°C meter (pHep by HANNA, model HI 98127) respectively.

Results

Source Water and Supply Water Quality

Significant reductions of EC from the source to the supplied water in most of the RO plants have been observed (Figure 4). No or little changes on salinity have seen from source to supply in RPWS systems as only sand filter is used to filter pond water to remove turbidity prior to distribution system and low EC of source water has to be ensured before passing it to the filtration unit. The SIDKO plant has no efficiency to reduce high salinity. However, the SkyHydrant plants can reduce EC through the ultra-filtration process if only EC is at lower range in the source water. The EC of the source and supplied water of the MAR site are little higher than the acceptable drinking limit, whereas EC of most of the supplied water are within acceptable range (Figure 4).

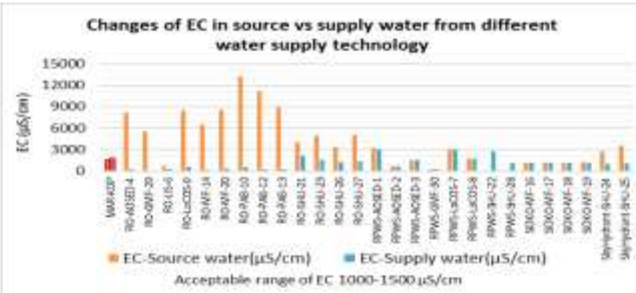

Figure 4: Changes of EC in source water and supplied water from different water supply technologies in three coastal districts of Bangladesh (MAR site is marked as red)

The significant reduction of Cl^- concentrations from source water to supplied water have been found in most of the RO and SkyHydrant plants. On the contrary, RPWS and SIDKO systems showed almost no change of concentration of Cl^- in both source and supplied water since these systems are not equipped to reduce salts. Three RPWS sites displayed Cl^-concentration a little higher than the safe limit in their supplied water (Figure 5a). Although increased concentrations of Na^+ in the supplied water was seen in some locations compared to the source water, Na^+ concentration of the supplied water of all the water supply options are within safe drinking water limit (Figure 5b). Despite both Cl^- and Na^+ concentrations in source and supplied water of MAR site were observed unchanged but all are within safe drinking water limit (Figure 5a, b).

The significant reduction of As concentrations from source water to supplied water have been observed in four RO plants and one SkyHydrant plant (Figure 6a). However, there is an unusual exception found in one RO plant (AOSED-4) that As concentration in supplied water was unexpectedly increased relative to source water after the treatment, which was also supported by the field test. Some chemical additives used in the treatment process may cause this abnormal rise of As and merit attention from the management authority.

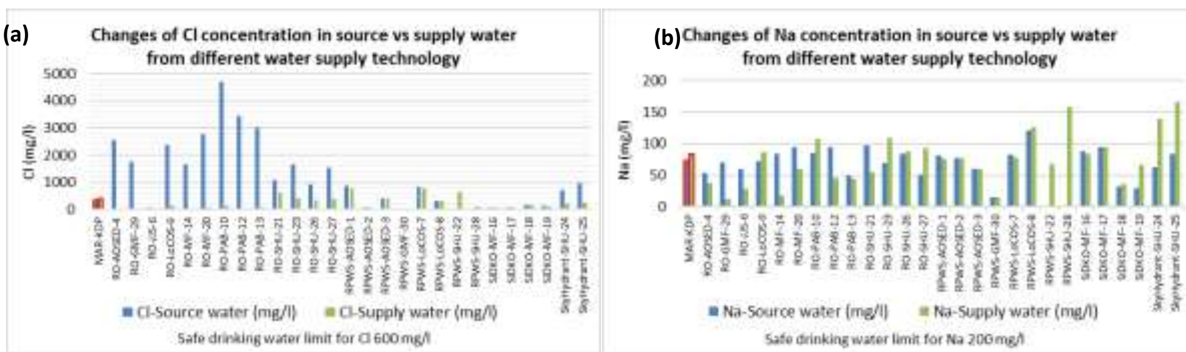

Figure 5: Changes of (a) Cl^- and (b) Na^+ in source and supplied water from different water supply technologies (MAR site is marked as red)

The noteworthy decreases of Fe concentrations (total) in supplied water have been seen in three RO and all SIDKO AIRP plants (Figure 6b). Moreover, the As and Fe concentration of the supplied water from all the technologies were found within safe drinking water limits, except one RPWS plant (SHU-22) (Figure 6a, b), which distributes groundwater from deep tube well without any treatment. It is likely that these high arsenic and iron coming from the aquifer that is already as contaminated. Supplied water from the MAR site was arsenic-free, but Fe concentration exceeded the permissible limit compared to the source water (Figure 6a, b), probably due to the shallow aquifer geochemical reactions.

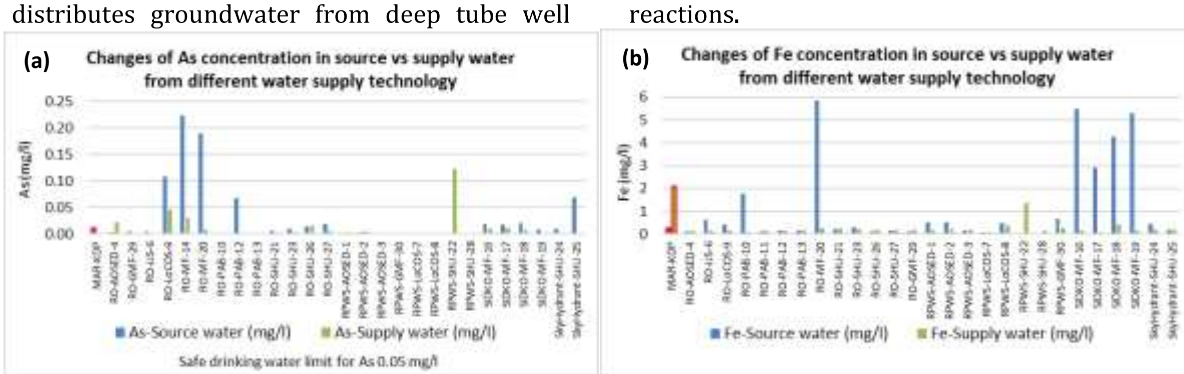

Figure 6: Changes of (a) As and (b) total Fe in source and supplied water from different water supply technologies (MAR site is marked as red)

Installation Cost

The installation cost of RO ranges from BDT 12,00,000-2,75,00,000 and SIDKO plants range from BDT 5,50,000-2,00,00,000 (Figure 7). On the other hand, the cost of RPWS installation varies from BDT 4,75,000 to 44,00,00,000 depending on their size and capacity of water supply. The implementation cost of SkyHydrant technology was BDT 11,40,000, where the community contribution was BDT 75,000. Contrary to other water supply technologies, installation cost of the modified MAR system at KDP site has been calculated as BDT 2,50,000 to 3,00,000 (Figure 7).

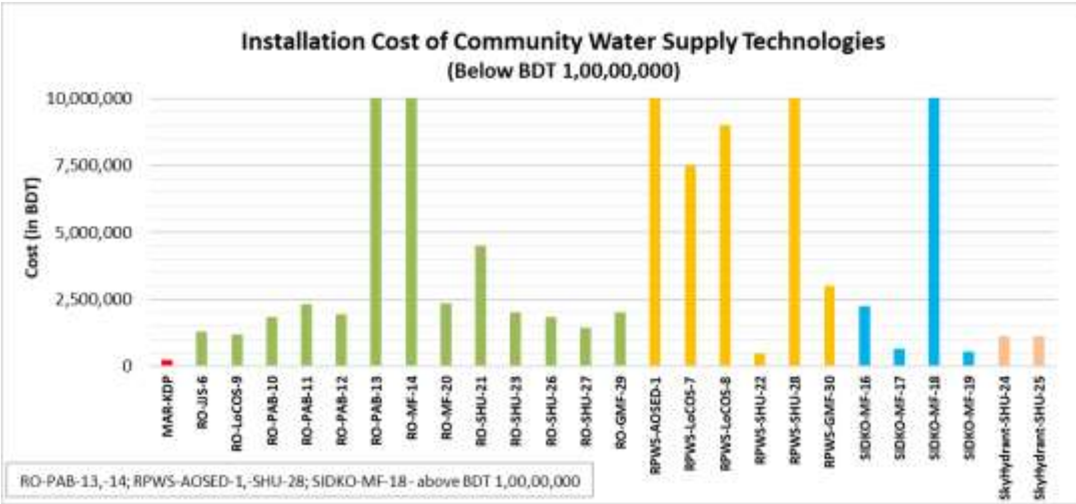

Figure 7: Installation cost (below BDT 1,00,00,000) of different community water supply technologies

Source Water, Supply Capacity and Payment

In most of the RO plants, groundwater from both deep tube well and shallow tube well are used as source water. Only 3 plants out of 14 use pond and river water after treating through sand filter. The supply capacity of any treatment plant depends on the volume of water it can treat in a day or hour. A majority of the RO plants in the coastal area have the capacity of about 1,000-10,000 L/day. However, two RO plants (RO-MF-14, GMF-29) have high capacity (about 800-2000 L/hour). People pay 0.35 to 2.25 Tk/L to collect water (Table 1) from most of the RO installation sites either by cash on each collection or monthly payment. In addition, two RO plants supply treated water by vendors and one plant uses piped distribution system. LoCOS-9 RO plant supplies water free of cost.

The SIDKO plants mainly use groundwater from shallow tube well as the source water. The SIDKO plant MF-18, which has been installed by WaterAid, has a high capacity to treat water at 50,000 L/day and supply water using a piped distribution system by taking 0.3 Tk/L as per meter reading on monthly basis. The other three SIDKO plants have a capacity of treating water about 10,000 L/day and supplied water to beneficiaries by vendors who pay 0.3-0.5 Tk/L (Table 1).

In Bagerhat district, the Government-implemented large RPWS system (AOSED-1) can provide 5,00,000 L/day after filtering the water from three large pond reservoirs. Another large high capacity (3,00,000 L/day) RPWS system in Satkhira District (SHU-28), uses deep groundwater as a source. Two more RPWS systems implemented by the Government (SHU-22) and HYSAWA (LoCOS-8) also use deep groundwater andhave the capacity of 15,000L/day and 58,000 L/day respectively. The other RPWS systems use pond water as a source and are able to supply filtered water of 10,000 to 20,000 L/day. Community usually makes monthly payment for the piped water supply at different rates ranging from Tk.20 to Tk.250 based on the number of households covered (Table 1), e.g., about 1200 households are being served by the RPWS-AOSED-1 plant with a payment of Tk.250/household/month. At one RPWS plant people pay cash at the collection point, whereas two other plants do not charge any payment.

SkyHydrant plants supply treated pond water by removing turbidity and bacteria and has a capacity of 10,000 L/day. Individuals pay about 0.5 Tk/L to collect water from the plant (Table 1).

In the MAR system, the source is pond water or rooftop rainwater infiltrated into the shallow brackish aquifer through recharge wells after filtration using slow sand filter, and after a certain period of infiltration when groundwater salinity is reduced to drinkable limit, the groundwater is abstracted from the aquifer through recovery well. The supply capacity of MAR has been measured as 10,000 L/day and people pay 20 Tk/household/month (Table 1).

Community Perception

Community acceptance is a critical parameter for the success of any water supply technology. Communities typically prefer the technology where they can easily get the drinking water with a minimum charge. In addition, people are usually concerned about the other two parameters in the supplied water, i.e., smell and color. Some RO plants have bad odour in their source water that is usually removed after treatment. In addition, higher Fe concentration gives water a reddish appearance which sometimes make them unacceptable to the community even they provide good quality water. The SIDKO plants have been seen to lower Fe concentration along with reducing As, that eventually changes the color of water. Abstracted water from the MAR site was sometimes observed to have odour problem, but it can easily be removed by storing the water over a night before drinking.

Maintenance

Community-based water supply options need regular maintenance. Some RO plants are managed by the community and others by the Government or NGO. The WaterAid-implemented SIDKO plant is maintained by an NGO and the other three by individuals. The RPWS and SkyHydrant systems are mostly maintained by communities. The capacity loss and mechanical loss can happen if consistent maintenance is not provided. Sludge management is one of the most critical and important tasks of RO treatment plants. In the RPWS system, the rate of supply water can be reduced due to pipe damage and clogging problems. These maintenance costs might be higher sometimes and paid by the community people. Though risk of clogging is considered as one of the major issues for the MAR system (Sultana et al., 2014), managing clogging of the open infiltration wells of the modified MAR through backwashing using mechanical pumps has been found easier. The routine replacement of suspended fines deposited on top of the filtration unit can be performed more readily which lowers the maintenance cost relative to the other technologies.

Performance and Longevity

The performance during operation of any treatment plant is connected to its longevity. Every mechanical system has a specific lifespan. The RO, SIDKO-AIR treatment plant and the SkyHydrant are operated as mechanical systems and therefore, has a particular durability and lifespan, e.g., RO membrane 3-7 years (Johnson, 2006) and SkyHydrant membrane 5-10 years (Skyhydrant Specification Sheet) based on the application, even though maintained routinely and if maintenance tasks are not performed sincerely those might lose viability soon. Efficiency of SIDKO-AIRP can be declined by 10% in 3 years after installation (Sorensen et al., 2015). In contrast, the modified MAR is a sustainable water supply system with a relatively longer lifespan (20 years) if communities have adequate awareness to continue routine maintenance. The filtration unit is a PSF, where the pond water is being brought into the unit by using an electric pump and the filtered water then directed to infiltration unit (openinfiltration wells) through pipe network which

Table 1: Summary of the comparisons among different community water supply technologies in coastal Bangladesh

Technology Name	RO	SIDKO-AIRP	RPWS	SkyHydrant	MAR-KDP
Installation Cost (Tk)	12,00,000-2,75,00,000	5,50,000-2,00,00,000	4,75,000 to 44,00,00,000	11,40,000	2,50,000-3,00,000
Payment	0.35-2.25 Tk/L	0.3-0.5 Tk/L	20-250 Tk/month	0.5 Tk/L	20 Tk/month
Source Water	Pond/STW[a]/ DTW[a]	STW[a]	Pond/DTW[a]	Pond	Pond + Rain
Supply Capacity (L/day)	1000-35,000	4000-50,000	10,000-3,00,000	10,000	10,000
Supply Water Quality	Cl, As, Fe within acceptable limit	Cl, As, Fe within acceptable limit	Cl (some), As, Fe within acceptable limit	Cl, As, Fe within acceptable limit	Cl, As within acceptable limit
High Salinity Reduction	YES	NO	NO	NO	YES
As & Fe Reduction	YES	YES	NO	Sometimes YES	YES
Bacteria & Turbidity Removal	YES	NO	YES, if pond water is used	YES	YES
Year-round Availability	YES, if groundwater is used as source rather than pond	YES	YES, for DTW[a] source; NO, for pond water source	NO	YES
Cost Issue	Very High Expensive	Moderate expensive	High Expensive	Moderate expensive	Least expensive
Lifetime	Fixed, cannot work after mechanical damage	Fixed, cannot work after mechanical damage	Fixed, cannot work after mechanical damage	Fixed, cannot work after mechanical damage	Extended for some days even after infiltration put an end

[a]STW- shallow tube well; DTW - deep tube well

finally enters into the aquifer by gravity and does not involve any mechanical engagement. The tasks of cleaning and washing of filtration and infiltration units can easily be managed by the community people or caretaker. Moreover, as the MAR scheme is constructed using locally available materials, the filtration or infiltration unit can be repaired if needed with less difficulty. The water source of the MAR system, i.e., the pond can be re-excavated if required and the roof can easily be cleaned for rainwater once a year before the monsoon arrives. Overall, the modified MAR system requires a comparatively easy and low-cost maintenance.

Discussion

RO is a very effective treatment process in coastal areas to reduce the salinity of brackish or saline groundwater and provides the year-round water supply. The reduction of EC, Cl^- concentration and sometimes Fe concentration have proved the efficiency of the RO systems. However, the installation and maintenance cost of RO treatment plants is relatively high, the supply capacity is slightly lower, and the cost of water is slightly higher compared to the other technologies.

The SIDKO-AIRP is preferable for those locations where salinity is within drinkable limit, and Fe and As concentrations are high, as it cannot reduce salinity but can provide Fe- and As-free water throughout the year. However, salinity is one of the severe problems in the coastal areas, thus the SIDKO cannot be an appropriate treatment process for the high saline groundwater areas. Moreover, installation and maintenance costs are relatively high.

The RPWS usually supplies drinking water from pond after sand filtration or from deep tube well without any treatment. It provides water to the end user via pipe network and has wide coverage. Communities can get water free of cost or with a small payment. However, their development is confined to the areas of fresh deep groundwater or large pond reservoir which is not widespread in coastal regions. RPWS systems, using large ponds as source water, can face seasonal shortage of water as well as the salinity of pond water may increase during the dry season which cannot be treated by the sand filter. RPWS plants that provide groundwater by pipeline without any treatment may contain salinity, Fe or As. According to the water quality analysis, high As has been found in the source water of one of the RPWS systems which draws attention of water managers.

The SkyHydrant is a relatively new technology in the coastal area as an alternative to PSF (pond sand filter), which significantly removes pathogens and turbidity from pond water. It is a single lightweight compact portable unit, fast set up, easy to operate, and filtration process does not require power or chemicals. The entire operations are simple and manual. Although the SkyHydrant is not designed to remove salt, Fe or As from source water, it still can reduce EC of pond water to some extent through the ultra-filtration unit. However, if these contaminants are present at high levels the water may not be suitable for filtering through SkyHydrant. In addition, this water supply technology mainly depends on pond water availability, thus it may face the seasonal problems of source and supply of water. The implementation cost is slightly higher.

MAR schemes have been tested and proven successful and are being operated through communities in the remote areas of coastal districts where the other technologies are less capable to function due to high salinity of source water and inaccessibility of transferring machineries. The key aim of the MAR system in coastal areas is to store fresh water in underground aquifers through a sustainable infiltration system in order to reduce the salinity of groundwater and abate the seasonal problem of getting safe drinking water. The MAR technique is able to infiltrate a large volume of treated water (10,000 L/day) into the underground during monsoon. As a result, groundwater EC is reduced by mixing of rainwater and/or filtered pond water, and the community can get fresh or much less saline water even at the dry period. Arsenic concentration of groundwater has also been observed to decrease considerably due to high infiltration and mixing of fresh water. Moreover, the MAR system is comparably low-cost technology as it uses the local materials with easy maintenance and is of high capacity and can be accessed with nominal payment. In addition, the construction cost of the filtration unit is very low in MAR compared to other technologies as it utilizes the advantage of abandoned PSFs. It also creates the opportunity to reuse hundreds of abandoned PSF which are widespread in the coastal areas. Moreover, the abstraction is very easy by using a hand pump. Furthermore, it is disaster resilient as the stored fresh underground water remains safe, even when there is inundation due to storm surges, and can be abstracted through recovery wells during emergency.

Despite the long list of advantages of the MAR system there are some challenges associated with the site selection, ambient groundwater chemistry as well as operation and maintenance. The site selection of the MAR system largely depends on the local subsurface hydrogeological setting (i.e., clay layer at the top of a confined aquifer, thickness of the clay layer) and ambient groundwater conditions (i.e., brackish groundwater in the target aquifer, salinity of the source water, the concentrations of arsenic and iron in groundwater) which make the technology confined to specific sites. The implementation, operation, and performance also depend on freshwater pond availability, skilled drillers, infiltration rate and community participation. Moreover, the recovery volume of water never exceeds the infiltration volume in order to abstract only freshwater, which confines the water use to drinking purposes. Besides the physical clogging of PSF and infiltration wells, the chemical and biological clogging also possess risks on the operation of the MAR system (Sultana et al., 2014). Sometimes the management of clogging can be time consuming and labor intensive when performed manually.

Conclusion

There are several newly introduced water supply options located in the coastal districts of Khulna, Satkhira, Bagerhat to mitigate the scarcity of safe drinking water. This comparative study among the MAR and other four water supply technologies has been conducted based on a questionnaire survey on several facts related to both on source water quality and supply water quality, types of source water, water supply capacity, installation cost, water pricing, distribution and payment system, operational status, management authority, community acceptance as well as laboratory analysis of source water and supply water chemistry. These technologies supply either fresh (reduced salinity), or As- and Fe-free, or turbidity- and bacteria-free water to the communities, mostly on payment basis. But most of these technologies are site-specific, installed comparatively at high cost, require expensive maintenance, and have fixed lifetime. Not all the technologies fulfill the requirement of desired quality of water for drinking purpose. Contrary to those technologies, despite having some challenges the modified MAR technique has been recognized as a successful alternative and sustainable disaster-resilient option that provides year-round good quality water at low cost, which is much needed for reducing salinity and increasing access to safe water for the coastal communities in Bangladesh.

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