Bangladesh CTCN-TA Project

Potential application for purification of saline water at household level

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1. Introduction

In the first report, detailed assessment, filed investigation, and literature review have been conducted pertinent to selecting the appropriate purification technology in the project area. From stakeholder's consultation, there was also various interesting soft components to be included in the final selection. All technologies have their own advantages and limitations. This report combines the information from the previous assessments and use a sustainability tools to ultimately pick the appropriate desalination technology. In coastal provinces of Bangladesh, saline water flows into the groundwater and forms an ion concentration above the drinking water standard of Bangladesh (EC 800 µs/cm). For example, in September 2018, in a field survey of the CTCN-TA project, the electrical conductivity of groundwater in Moraqacha village and Balia village in Sathkira were 2,450µs/cm and 2,310µs/cm, respectively, which exceeded drinking water standards. Accordingly, the TA water team conducted desalination performance tests to propose a solution for a household water purification system that could remove the salt from groundwater in the southern coast of Bangladesh. For these tests, they constructed a capacitative deionization (CDI) device that removes ion in water by electrical adsorption and desorption, and a reverse osmosis (RO) device that removes microorganisms, heavy metals, and ion components in water using the reverse osmosis principle. In addition, the amount of water produced by the CDI and RO systems was measured according to salinity concentration, and the RO purification device cost and maintenance cost were also calculated

2. Summary of shortlisted candidates for selection of best purification technologies

As per the detailed field study, office discussion, stakeholder's consultation, and detailed literature review on the state-of-the-art purification technologies, the final list of candidate technology has been shortlisted along with their typical advantages and limitations. Generally, over 10 desalination technologies have been considered from the detailed assessment. However, only 4 has been found most relevant to this project (see table) and sustainability-based selection criteria has been employed to ultimately pick the final best two technologies.

Table 1. Attributes of short-listed purification technologies

Type of purification technology	Benefits	Limitations
Capacitive deionization	• High water recovery (85– 90%) • Energy-efficient for brackish water desalination (<3500ppm) • Reduced environmental impact compared with RO • Operating power comparable or Lower than ED technology. • Design simplicity: require switching of polarity and water consumption for cleaning • Availability of option for renewable solar and wind energy	• Early-stage technology: - Not widely available today but becoming more available over time in countries - carbon electrode manufacturing not yet well commercialized - Replacement parts may need to be imported - High capital cost
Solar still distillation	• Simple design • 100% solar-powered • Low maintenance and operational costs • Minimal environmental impact • Can be used for both seawater and brackish water desalination • Good for household level	• Large land requirement • Low output volumes • Output dependent on weather • High capital cost
Reverse Osmosis	• Commercially mature technology: • Widely available • Easy access to replacement parts • Reduced capital cost • Energy-efficient for seawater desalination, but can also be used for inland brackish water • Operating power: Lower than ED technology for > 5000ppm • RO unit can be easily re-configured • Availability of option for renewable solar and wind energy	• Low water recovery rate: - Single-pass (25–50%) - Multi-pass (~80%) • Extensive pre-treatment and maintenance needs • Large waste volumes and associated environmental impact • RO membranes are sensitive to chlorine and also fouling and scaling a big problem
Reverse electrodialysis	• High water recovery (85– 90%) • Energy-efficient for brackish water desalination (<3500ppm)	Mature technology but optimized for industrial processes: - Not widely available for drinking

	• Reduced environmental impact compared with RO • Design simplicity: recirculation required but low pressure, no pressure vessels • Materials available for easy prototype: • Availability of option for renewable solar and wind energy • Operating power: low for low salinity area (<5000ppm)	water treatment - Replacement parts may need to be imported - High capital cost - high membrane cost, additional cost with potential of titanium

3. Prioritization and selection criteria for the best purification technology

The most important prioritization criteria toward establishment of any community-based project should emanate from the point of view of creating a sustainable community. Sustainability is most often defined as meeting the needs of the present without compromising the ability of future generations. Establishment of sustainable engineering project in a community must address four major pillars which are equally important to the well-being of the project. These pillars include the socio-cultural and political sustainability, economic sustainability, environmental sustainability, and technical sustainability. A certain project setup, construction of engineering works, and/or selection of a desalination technology options have to also address the requirement of all these pillars in order to sustainably serve the community for the desired period of time (see Fig. 1).

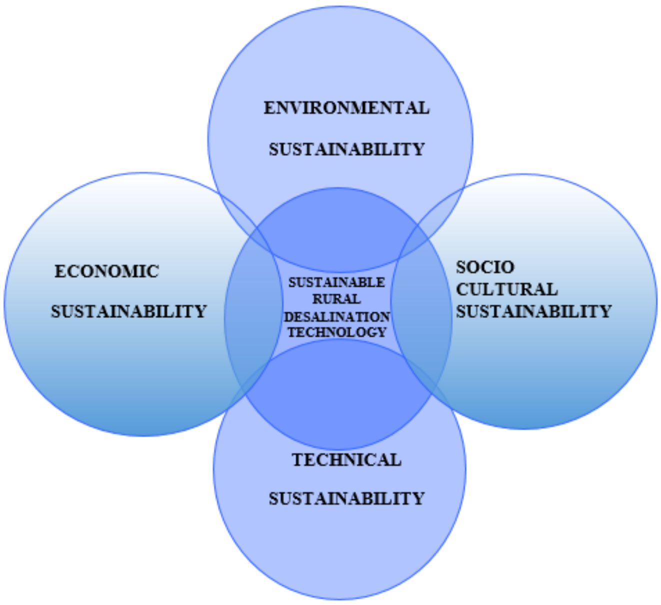

Figure 1: Sustainability based prioritization technique for selecting purification technology

Description of the four sustainability pillars for establishment of purification technologies has been described based on the context of the target community. A purification technology which fully satisfy these criteria can be a very good solution toward solving the community-based desalination technique selection. Considering the sustainability increases the ownership of the project and ensure long time healthy usage by the community. In this section all the short-listed technologies has been evaluated in light of the four sustainability pillars and the final two most relevant technologies has been identified with the stated reasons.

Socio-Cultural sustainability:

The household and community-based technology to be selected should be well accepted by the community. This pillar ensures the acceptability of the technology with in the community and its compatibility with their indigenous knowledge, tradition, history, culture, and social norms. The sustainability of a rural water technology depends on the willingness of users to provide the necessary time, money and labor to keep the system functioning. This willingness may be affected by socio-economic factors such as income level, ethnic homogeneity, or the willingness of villagers to work together. More commonly, however, the willingness will depend on their satisfaction with the technology, usually compared to the previous purification technology in the community. When communities perceive a significant improvement in water services, they are usually more willing to pay for O&M. Willingness-to-pay is also affected by community perceptions of ownership or sense of entitlement to free services from the government. Moreover, the technology has to also be well accepted by all involved stakeholders and beneficiaries as it directly or indirectly affects them. This component of sustainability also involves establishment of community based technical, financial, and management committees administering the water point and empowering them how to take care of the established infrastructure because when a new technology comes in, it takes a long time to learn it. With the social sustainability the project implementing body has to also answer the question ‘Is there really the technology demand in the community? Is the water purification technology a priority question in the community? Did the community owe the right awareness on the water quality and its health hazard? otherwise whatever big money is invested; the project and the technology may not be sustainable.

When we evaluate the actual site situation in our project area, there is high demands for appropriate purification and housing technology especially in the rural areas of the coastal region. It is also observed that the past and currently on-going projects have faced various obstacles during the implementation. Absence of the source of financing to cover the operating and maintenance (O&M) cost; capacity and experience to conduct the O&M; risk of low social acceptance to new technology; and low public awareness on the water quality have been the main bottle neck. There are around 15 per cent of the respondents who said that the reasons for not using public drinking water facilities were: the cost, bad taste, and long distance.

Generally, the community in this area has big request for the appropriate purification technology. Most of them already understood the health effect of high salinity water and they are ready to put all their effort and energy to care for any desalination option coming to their village. In addition to this all the short-listed purification technologies viz. Capacitive deionization, Solar still distillation, Reverse Osmosis, and Reverse Electrodialysis have been more or less attempted once in those coastal areas of Bangladesh and there will be high propensity the community will adapt them. However, the reverse osmosis process will have relatively higher likelihood as it is currently practiced everywhere, and everyone have seen or heard about it. The rest technologies might have almost same popularity. Typical example strengthening the social sustainability was observed during stakeholder's consultation. The Nowabenki Gonomukhi Foundation is a non-profit management organization accelerating finance for the rural community. It is a partner organization of PKSF with experience in providing clean water to coastal areas of Satkhira and Bagerhat. District leaders of these area stated that water treatment plans for purifying water and serving pure drinking water to the habitants of the Satkhira district was established using reverse osmosis process. The technology was tested by BUET and certified by BSTI. NGF has been monitoring marketing and maintaining the project and machines for more than 4 years.

Economical Sustainability:

This term refers to the sustainability of the project in terms of financial and economic aspects. It answers the question 'can the community afford to pay for the establishment and running cost of the specific purification technology?'. This includes different segments (geography, management model) having a different level of cost recovery through tariffs; Identification of fund sources and responsibility for major repairs, capital maintenance, and asset replacement, running and operation costs with special attention to the social pricing for the most vulnerable groups as well to ensure affordability. The total cost of a desalination facility is broken down into capital expenditure (CAPEX) and operational expenditure (OPEX). Both CAPEX and OPEX are highly dependent on the location of the treatment facility and vary considerably for small-scale systems. OPEX is primarily dependent on energy costs, which can be reduced by using charge-based technologies instead of RO for low-salinity brackish water desalination (<3500) or by powering the facility using renewable energy sources. Since RO is a more mature technology than CDI and EDR, it has lower CAPEX, and it dominates the current desalination market. Generally, solar-powered RO involves a costlier initial investment than grid-powered RO, but it has greatly reduced operating expenses. Both EDR and CDI have lower brine disposal and replacement costs due to their high-water recovery rates and the longer lifetime of membranes, which makes them more attractive for communities that do not want to pay significant reoccurring costs. In terms of cost, the decision about which technology to choose should be based on the community's ability to invest (CAPEX) and its ability to sustainably operate and maintain the facility (OPEX). In this project area, PKSF suggested many public drinking water supply facilities have been installed; however at least 90 per cent of them are not being operated due to lack of proper maintenance for various reasons. DPHE has also conducted a variety of fundraising activities to supply and install water treatment devices in the southern part of coastal Bangladesh. However, due to poor economic conditions of the people of Satkhira, only 35 per cent of respondents were willing to pay for safe drinking water, and the rest were unwilling to pay for drinking water. The situation seems that the willingness to pay is low and a technology with low running and operational cost has to be better suggested. In economical aspect, RO seems of lower CAPEX and easily available technology. Moreover, if operated with renewable energy sources and for highly saline water, RO will be the first choice followed by the CDI and ERD technology. Solar still distillation would be the least priority for its lower yield and relatively higher CAPEX.

Environmental sustainability:

This sustainability pillar mainly ensures that the rate of waste generation from the desalination technology to be selected should not exceed the assimilative capacity of the environment (sustainable waste disposal). The most common environmental problem linked to desalination emanates from the energy source required to run the technology as well as from the brine disposal. Most desalination facilities today are powered by fossil fuels, either by the electricity grid or by a diesel generator. The advantage of fossil fuels is that they are reliable, making production consistent and dependable. Their main disadvantage is their chemical by-products, which are harmful to the environment and to human health, both immediately and in the long term. Tapping into the grid is an obvious choice if electricity is cheap and dependable. If the community is off-grid, then the choice is between a diesel generator and various renewable energy sources. However, dealing with intermittent energy sources requires either energy storage or energy back-up. Conventional energy storage would mean a battery, which stores extra energy when the source is supplying power, but the plant is not operating. An alternative option is to build an oversized facility so that extra water can be produced and stored in a reservoir for consumption when there is no power. Although there are various new types of battery, the only options that are currently cost-effective are lead-acid batteries. Used batteries must be appropriately recycled; the improper disposal of lead-acid batteries has significant environmental impacts and can contaminate local water supplies. Unfortunately, more often than not there is no recycling or safe battery disposal process in place for small communities in Bangladesh.

Both EDR and CDI have lower brine disposal and replacement costs due to their high-water recovery rates and the longer lifetime of membranes, which makes them more attractive for communities that do not want to pay significant reoccurring costs. ED and EDR can also be easily adapted to be powered directly by photovoltaics, making them environmentally sustainable and technically feasible for off-grid communities. SSD generally has very small environmental impact as compared to the other candidate technologies mainly because it is based purely on solar energy and associated brine and chemical disposal is also relatively limited. CDI and EDR has reduced environmental impact as compared to RO. RO has relatively large waste volumes and associated environmental impact but investing in higher-quality membranes and/or multi pass systems can help reduce water waste and make RO more environmentally friendly and water-efficient

Technical Sustainability:

Technical issues related to the design and construction of rural desalination plant are the most obvious determinants of purification technology sustainability. With this sustainability pillar, one can ensure that the selected purification technology is technically sound, scientifically proven, commercially available and can easily be installed and operated in the project area without any failure. This includes proper site selection which addresses duplication of efforts with other implementing bodies, government and NGOs; avoiding flooding areas during site selection that complicate construction works; and addressing water to all parts of the community. The site we decide to establish the desalination plant definitely affects the type of purification method to decide. SSD can not be installed if there is no solar energy source. If the number of communities to be served is very small, the technology to be selected should also be household technology such as SSD and we can not establish RO in such cases. In this project area, during stakeholders consultation, it has been stated that it would be better to focus on the household level desalination technology solutions needed for Bangladesh's coastal areas, and that if new technologies are introduced, then another complex procedure would be needed for the actual users—the local residents—to learn and use the new technology or equipment. Unlike household water purifiers, the public water facilities should be installed in public places such as schools and made available to many local residents. The other important technical issues to consider in the technology selection is the ability to remove all impurities. The problem of water quality in the coastal zone is not limited to its salinity but also has to be capable of removing iron, arsenic, and other impurities. The technology selection has to also make sure that the demand of the target community has been met. As to the commercialization, EDR and CDI technologies are in the early stages of commercialization, which is reflected in their wide ranges of capital cost. However, in general CDI and EDR are likely to be twice as expensive as conventional RO units, with significant additional costs if they are powered by renewable energy sources. On the other hand, while SSD has minimal to no operating costs, it has a very high capital cost per liter due to its very low daily output rate, making the technology less attractive for low-income rural communities. The main issue for CDI and EDR is that they are not mass-produced and have not been optimized in the way that RO has. A technology review of CDI in 2013 found that in terms of capital cost an 'RO system capable of treating 1,000 L/h costs between $3,000 and $4,000 whereas a similar capacity CDI system costs about $10,000. Apart from SSD, which requires solar energy, all other desalination technologies can be powered by almost any source of energy (fossil and renewable sources). The decision to utilize a renewable energy source is determined primarily by the location, but it also depends on the community's access to additional capital for installing renewable power facilities and units for energy storage and back-up, and the additional technical capacity required for maintenance. SSD has very low water production volumes, with most units producing only 2–35L/day, which is only enough to supply water to 1–5 individuals. It is possible of course to install numerous SSD facilities, but this requires excessive land area and capital investment. However, this technology might be a good option at household level.

4. Contextually relevant best desalination technology options

Various purification technologies identified from the overall site study, direct field visit, and literature review has been examined in light of sustainability criteria. Accordingly, the overall recommendation of the desalination technology for the targeted areas of Bangladesh would be the RO and CDI. Because RO is the most widely commercialized, least expensive and most technically researched and optimized option well known in the area. In an alternative to RO, CDI is recommended for low salinity (<3500) brackish water sources because it has low energy consumption, is inexpensive to produce and semi-commercialized and can be available on the market. Technical and cost details of both the RO and CDI process has been addressed thoroughly in the following section.

4.1 Capacitive Deionization (CDI)

CDI removes ionic species in saline water by applying an electric potential to porous electrodes. The CDI process has several advantages over conventional desalination processes, including efficient energy use, eco-friendliness, and a high recovery rate. In general, the CDI cycle consists of two steps, charging step (purification step) and discharging (regeneration step).

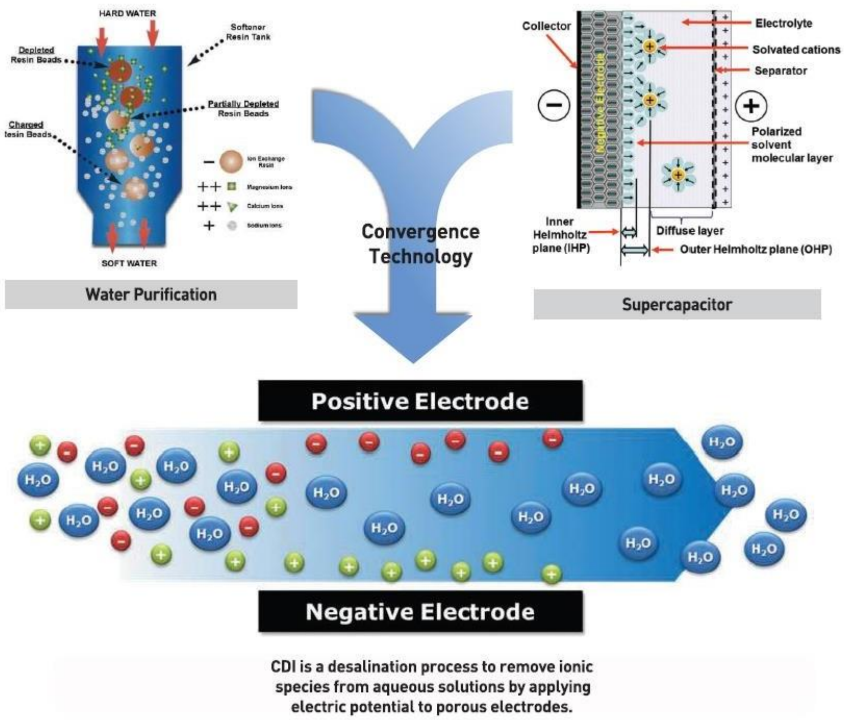

Figure 2: Ion removal principle of CDI device

In this experiment, the TA water team examined the overall desalination efficiency of CDI according to the change of salt concentration (electrical conductivity: 1000-3000 μs/cm). Ultimately, the TA water team examined if the salt can be removed to 500 μs/cm, lower than 800 μs/cm, the water purification standard of Bangladesh.

The CDI device tested for desalination performance showed a cycle of alternately producing wastewater and purified water. Periodic voltage (adsorption (1.5V) / desorption (-1.5V)) fluctuations occur during the generation of purified water and wastewater. In this experiment, the adsorption / desorption cycle was set to a two-minute cycle. In reality, the purified water was measured to be generated for 45 seconds and the wastewater for 20 seconds.

The CDI device consists of 1) a CDI module in which electrical adsorption / desorption takes place, 2) an electrical circuit board to control the process and device of adsorption / desorption, 3) a solenoid valve to automatically discharge purified water / wastewater, and 4) a pump (DC 12V, 5A) for supplying the raw water and a pressure reducing valve for maintaining constant water pressure.

Figure 3: CDI device for desalination performance test

From the CDI desalination test results, the device showed stable treatment efficiency after approximately 20 cycles (Fig. 4), and electrical conductivity was measured after at least 30 cycles of operation.

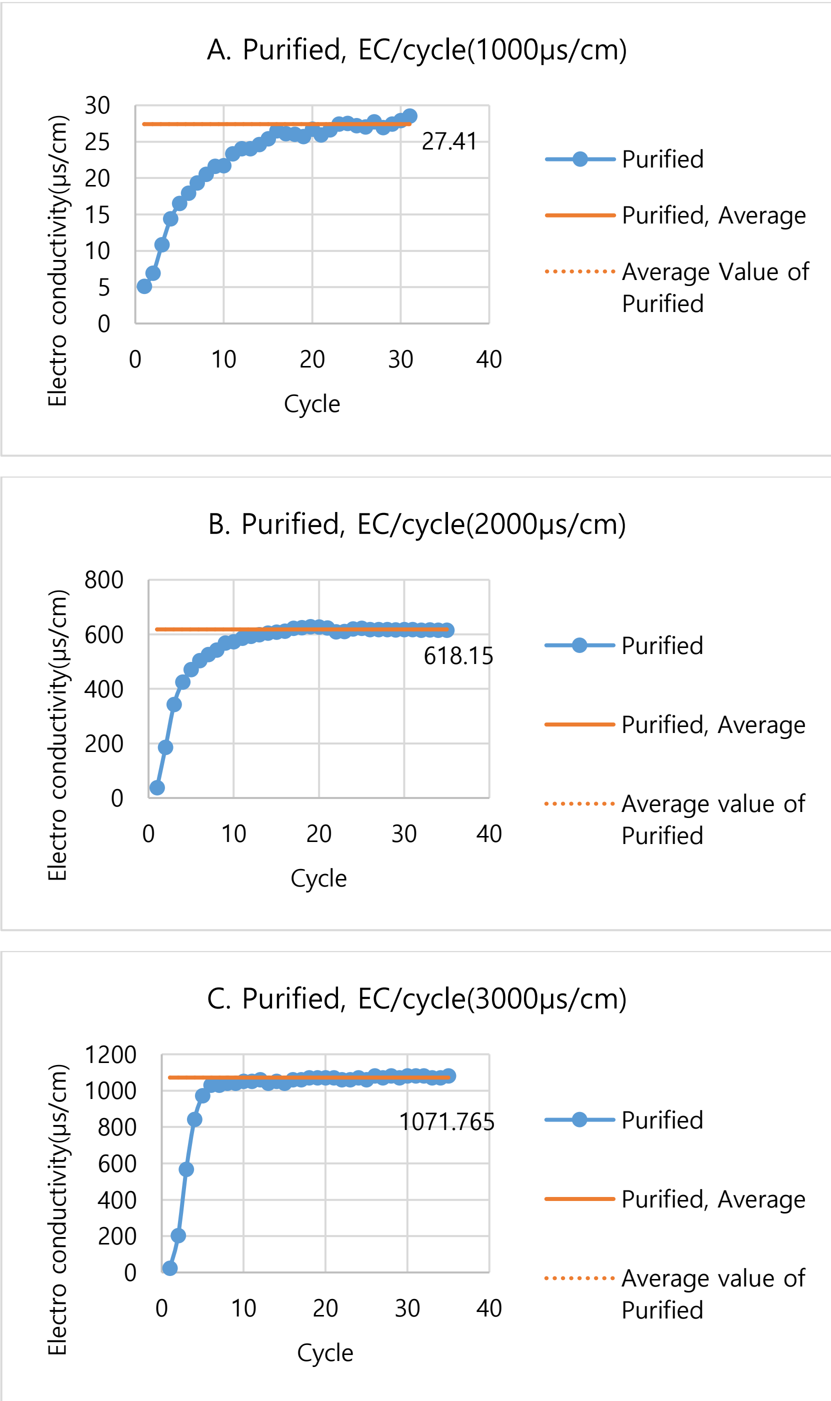

Figure 4: Electro conductivity curve according to CDI device repeated operation.

In addition, the desalination performance of the CDI device was measured according to the adsorption time for a total of 45 seconds (Fig. 5). In the case of saline water of 1000, 2000, and 3000 µs / cm, maximum adsorption performance was observed between 20-40 seconds, 15-30 seconds, and 20-40 seconds after the start of adsorption, respectively. The electrical conductivity of the desalinized water was measured as the average value of the water from the adsorption.

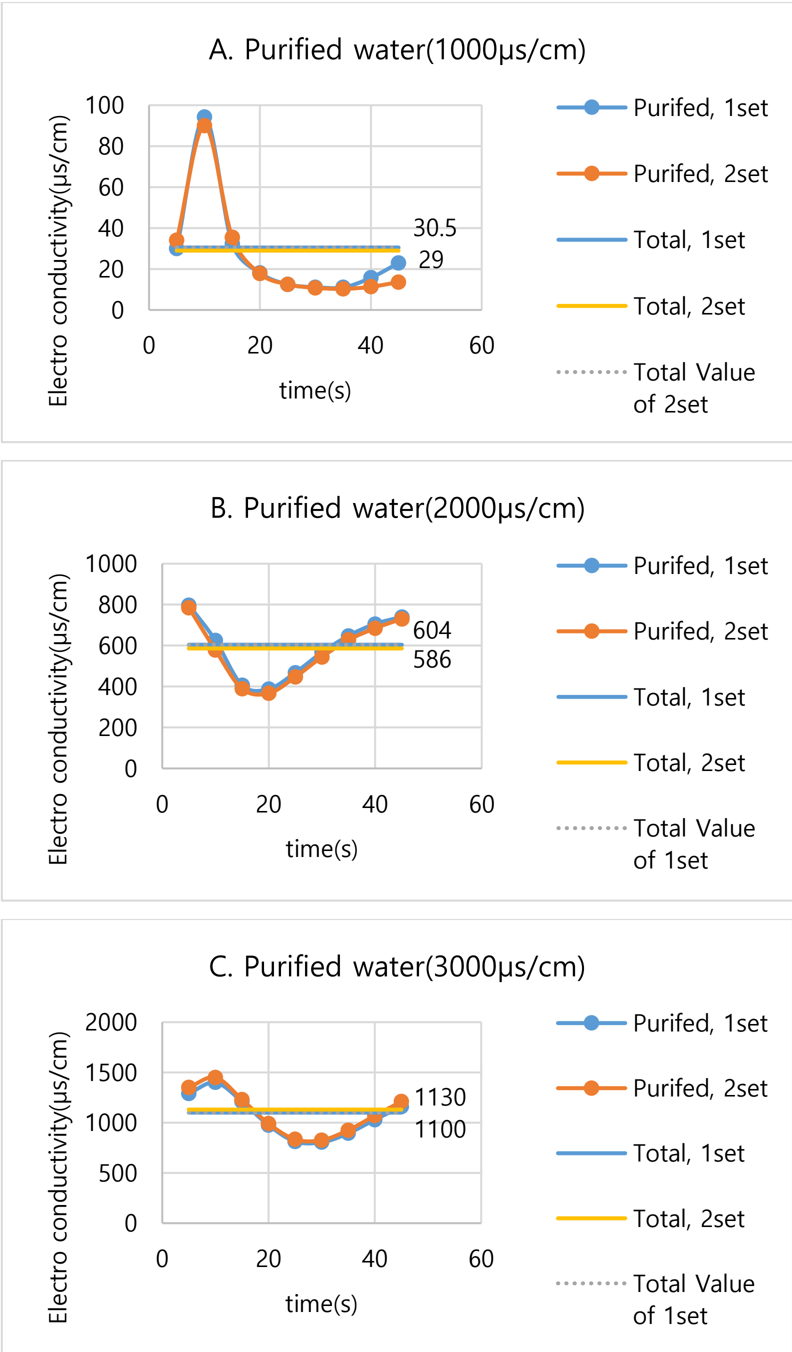

Figure 5: Variation of electro conductivity over time in adsorption of CDI devices

Table 2 summarizes the results of the experiments on saline water with an electrical conductivity of 1000-3000 μs / cm using a CDI device. In the case of saline water with an electric conductivity of 1000-2000 μs / cm, the treatment efficiency according to process time satisfies the drinking water standard value (less than 800 μs / cm) of Bangladesh with only one treatment. For higher concentrations (EC 2500, 3000μs / cm), the first stage treatment resulted in drinking water exceeding standard value, so the second treatment was added to manage salt level to below the drinking water standard value. Thus, if a CDI water purification system is applied to Bangladesh, it would be necessary to design the first or the second stage equipment considering the concentration of groundwater salinity depending on the region and dry and rainy seasons.

On the other hand, in the case of saline water with a concentration of 1000-2000 μs / cm, the first stage configuration, 2.7 to 3 L / hr of drinking water was produced through the CDI device; in the case of 2500 and 3000 μs / cm saline water requiring the second stage configuration, the primary treated water of 2.7 to 3L / hr was produced in the first stage, with 3L/hr produced in the second stage. When producing drinking water below the drinking water standard, the equipment configuration and drinking water production time will be more than twice as long in the second stage configuration.

Similar results were shown in the power consumption of the device. That is, in the saline water desalination experiments, as the concentration increased, the real-time power consumption tended to increase from 30 W to 37.9 W. However, in case of saline water of 2500 and 3000 μs / cm compared to saline water of 1000-2000 μs / cm, more than twice the power was consumed with a second stage configuration. As a result, in the case of a desalination system using a CDI device, groundwater with an electric conductivity of less than 2000 μs / cm was more suitable.

Table 2. Desalination performance and power consumption of CDI devices

Classification		EC1000	EC1500	EC2000	EC2500		EC3000	
		1st stage	1st stage	1st stage	1st stage	2nd stage	1st stage	2nd stage
Electric conductivity	Raw Water	1020	1520	2030	2530	856.9	3010	1071.8

(µs/cm)	Purified Water	27.4	298.2	618.2	856.9	12.5	1071.8	22.4
Production of Purified Water (L/hr)		3	3	2.7	2.7	3	3	3
Real-time power consumption (W)		30	32.6	36.4	37.5	36	37.9	31
Power consumption (kWh/ton)		10.0	10.9	13.5	25.9		23.0	

4.2 Reverse Osmosis (RO)

Reverse osmosis has been in use for more than 50 years to remove impurities from water by retaining solvent molecules on a semi-permeable membrane. Reverse osmosis filtration is one of only a few available methods to remove particles of molecular size, such as ions and bacteria. To achieve the separation, an external pressure is applied to the contaminated solution that is higher than its osmotic pressure, reversing the natural process of osmosis that wants to create a concentration equilibrium. The RO membrane is a versatile tool. The size of RO filtration systems varies with its applications, ranging from bottle-sized personal systems for water purification to the large-scale plants for desalination or industrial water treatment

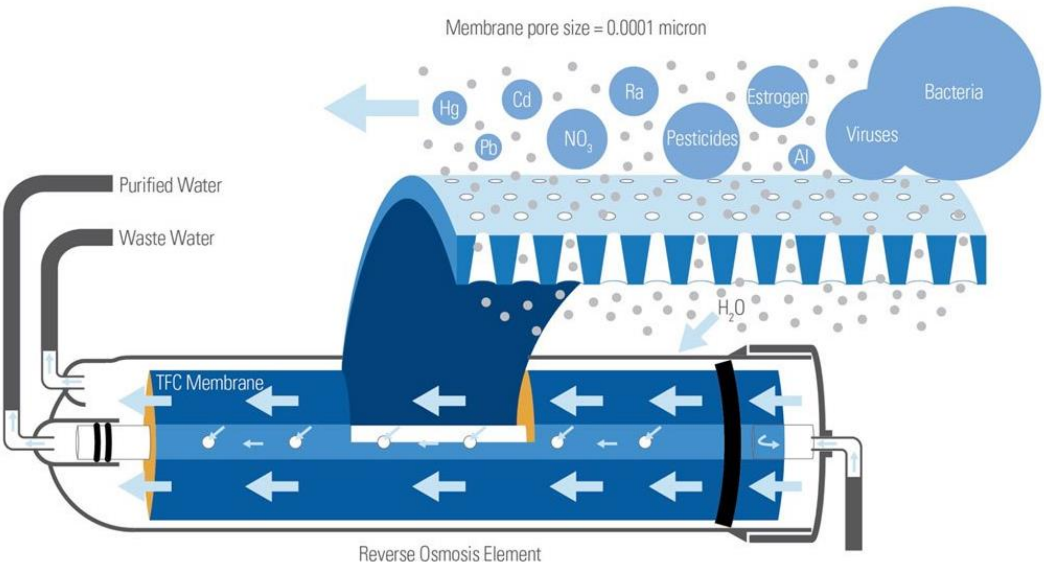

Figure 6: Schematic of small reverse osmosis filter

Similar to the desalination performance test of the CDI device, the TA water team examined the change in the overall desalination efficiency of the RO device according to the concentration of the saline solution (electric conductivity: 1,000-6,000 µs / cm). Ultimately, the TA water team examined if the salt can be managed down to 500 µs/cm, lower than 800 µs/cm, the water purification standard of Bangladesh.

The RO water purification system tested for desalination consists of 1) a sediment filter, cation exchange filter, carbon filter, and UF filter, 2) an RO filter, and 3) an RO booster pump. In this experiment as well, saline water of 1,000-6,000 µs / cm was prepared using refined salt as in the CDI device experiment, and desalination performance was tested by adding the RO filter and dedicated booster pump to the basic water filter configuration.

Figure 7: RO device for desalination performance test

Unlike the CDI device having an electrical adsorption / desorption process, the RO filtration system constantly filtered the salt component through the RO membrane and maintained a constant treatment performance after about 5 minutes. Accordingly, desalination performance was tested after operating the RO water purifier for at least 10 minutes, and the results of the desalination performance and power consumption of the RO water purifier according to the saline water concentration, the raw water, are shown in Table 3.

Table 3. Desalination performance and power consumption of RO devices

Classification		EC1000	EC2000	EC3000	EC4000	EC5000	EC6000
Electric conductivity (μs/cm)	Raw Water	1050	2070	3090	3980	5000	6050
	Purified Water	74	151	294	463	660	900
Production of Purified Water (L/hr)		9.6	7.5	5.4	4.5	3.6	2.6
Real-time power consumption (W)		29.38	29.58	20.58	20.61	20.89	21.18
Power consumption (kWh/ton)		3.06	3.94	3.81	4.58	5.80	8.31

In this experiment, saline water with an electric conductivity of 1,000-5,000 μs / cm satisfied the standard value of drinking water in Bangladesh (less than 800μs / cm), and in case of saline water of 6,000 μs / cm or more, the second stage treatment is needed. It is notable that in the case of saline water of 1000 to 3000 μs / cm, not only is the treatment efficiency better than that of the CDI device, but also salt component can be managed down to below the drinking water standard through the first stage treatment up to a high concentration of 5000 μs / cm of saline water.

On the other hand, drinking water production per unit hour of the RO device was 2-3 times higher than that of the CDI device treating at similar concentrations at 3.6-9.6 L / hr. Moreover, a smaller amount of power was consumed; power consumption per unit of drinking water produced was reduced by more than three times. As a result, the RO purification system was superior to the CDI system in terms of treatment performance, treatment range, and power consumption for salt component removal. Of course, it is necessary to test the treatment performance with consideration of various ionic and particulate matter in Bangladesh groundwater.

5 Cost Comparisons of CDI and RO process

Comparison of equipment and maintenance costs of CDI and RO equipment

Table 4 summarizes the equipment and maintenance costs for the CDI and RO equipment. The overall cost varies depending on the components and processing efficiency of the two devices, as well as the replacement cycle and cost of consumables.

The CDI device costs $500 per unit; for concentrations of 2000 μs/cm or more, the cost for the main components of the second stage equipment (CDI base unit (module + circuit board), pump, water tank, etc.) amounts to $1000. Of course, CDI modules benefit from larger capacity and better processing performance, but this also increases equipment and maintenance costs. In addition, CDI module and pump are the main consumables of CDI device; while their consumption cycle varies depending on the concentration of the saline water in the groundwater, the costs of the module and the pump are about $250 and $50, respectively.

On the other hand, in the case of the RO device, the main components are the filter and the high-pressure pump; even when comparing the second stage equipment cost, it is less expensive and consumes less power than the CDI device. That is, even with the first stage configuration of $450, the second stage configuration amounts to $800 by adding the RO filter, booster pump, and water tank. It also has the advantage of consuming three times less power per unit production of drinking water because it consumes less electricity and produces more water than the CDI device. As we know, in terms of the costs of consumables, the RO pumps are rather expensive, and the filters are relatively inexpensive. However, they can become a cost burden if many filter replacements are required depending on the quality of the groundwater.

As a result, the quality of the groundwater flowing into the water treatment device is important in terms of not only the initial equipment cost but also maintenance costs as well. It will be necessary to consider not only household water purification equipment but also securing pretreatment facilities and utilizing rainwater harvesting facilities. At the same time, photovoltaic energy should be considered as well to help reduce power consumption and Bangladesh’s power shortages.

Table 4. Comparison of CDI and RO device costs and maintenance costs

	CDI device	RO device
Key components	1st stage device - CDI device(CDI module+Circuit board) - Pump - Water Tank(30L) 2nd stage device - 2 set of 1st stage device	1st stage device - Filters: Sediment + Ion-Exchange + Carbon + UF + RO - Booster Pump - Water Tank(30L) 2nd stage device - 1st stage device + RO filter + Booster Pump - Water storage tank(30L)
Device cost	1st stage device: $500 2nd stage device: $1000	1st stage device: $450 2nd stage device: $800
Cost of maintenance	1. Power consumption per drinking water production: 10.0~25.9 kWh/ton 2. Cost of replacing consumables per device - CDI module: $250 - Pump: $50	1. Power consumption per drinking water production: 3.1~5.8 kWh/ton 2. Cost of replacing consumables per device - Filter set: $120 - Booster Pump: $200

6 Gravity-driven membrane (GDM) filtration

Recently, an alternative membrane process, which is a gravity-driven membrane (GDM) filtration was introduced. GDM has several advantages such as non-energy required process, no need to apply a new membrane for the process, a non-cleaning procedure by chemicals, and etc. GDM process can operate long term operation due to biofouling on the membrane surface. The biofouling and biofoulants adhered on the membrane surface. However, the membrane does not need cleaning procedures. The biofouling and biofoulants can mitigate other fouling such as organic and inorganic foulants. Additionally, water qualities of the produced water were improved by biofouling on the membrane surface. Pollutants cannot penetrate biofouling layer and membrane layer due to the physical size of pollutants. Thus, the GDM process can reduce total amounts of energy, maintenance costs, fouling problems and improve water qualities. So, GDM process is one of the best options to apply for the household level.

7 Small-scale water purification plant and rainwater or stormwater tank as a village level for coastal areas

Although water purifier will be supplied for each household, the maintenance costs and the lifespan of the purifiers should be considered. In coastal areas, many people cannot purchase new filters and pumps every 6 months or 1 year for replacing the old ones in order to increase the lifespan of water purifiers. There are other ways to improve the lifespan of purification technologies, for example using common small-scale water purification plants in villages. 10 m^3/d water purification plant in a village can better water quality and supply people drinking water. It can also improve the lifespan of water purifiers in households.

Another way to improve the lifespan of water purifiers is to establish rainwater and stormwater tanks. Each household has a rainwater or stormwater tank, at least 300 L, which is useful for having a shower, cleaning dishes, laundry and so on. The way can reduce the burden of water purifiers in the household and can save drinking water for people. Additionally, if the 10 m^3/d water purification plant in a village mentioned above would be broken, the tank would help to supply water for the water purifier until the village purification plants would be repaired.

8 Concluding remarks

Although CDI and RO purifiers, which are suggested in this report, are a little bit more expensive than other RO purifiers sold in Bangladesh, they can produce better water quality than other purification technologies. In terms of maintenance costs and water qualities, RO purifier has a comparative advantage compared to CDI purifier. Thus, the report prefers to apply RO purifiers for coastal areas in Bangladesh. However, RO still seemed to be precious processes so that it could be reduced a cost of energy via several alternative energy harvesting processes like a solar panel. The solar energy connected with RO can be reduced by 1.0 ~ 3.5 kWh/ton, which means that a RO with a solar energy purifier achieves a power consumption of 2.0 ~ 3.0 kWh/ton. The RO with solar energy is, therefore, a suitable integrated system to make an energy efficient water purifier for water supply to coastal areas in Bangladesh.

Another option is to install GDM filtration process for reducing operation energy, nonchangeable membrane, and maintenance costs. So, the GDM process cannot apply a high pressure. Additionally, it can achieve the zero-energy process. The GDM process also exhibited improved water qualities due to a physical pore size of the applied membrane and biofouling on the membrane surface. The GDM process therefore is one of the proper water purifiers for the household level.

It is worth to note that the water purifier is not a perfect solution. The small-scale water purification plant and rainwater or stormwater tank should be established to help the lifespan of the water purifier and to supply better water quality to people.