Bangladesh

Aquifer storage and recovery technology for irrigation water supply

Case study prepared by:

Sara Nowreen

Focus

Bangladesh is one of the most vulnerable countries to climate change and the people living in its coastal regions face unique challenges. Once-abundant fresh groundwater has become more scarce and increasingly saline due to encroaching saltwater from the Bay of Bengal, rendering it undrinkable and unsuitable for agriculture.

Population growth, irrigation demand and rainfall variability (exacerbated by climate change), have put further stresses on groundwater. Warmer temperatures due to climate change, for example, increase the need for irrigation due to increased evapotranspiration (Döll, 2002), and in turn, more irrigation leads to more groundwater pumping.

Aquifer Storage and Recovery (ASR)

To address these issues, Bangladesh has adopted the Aquifer Storage and Recovery (ASR) technique, which involves storing fresh monsoon water underground and retrieving it during the dry season. Aquifers are expected to exhibit a significantly slower response to climate change fluctuations than surface water (Santosh and Raneesh, 2012) and thus provide enhanced water security.

More than 100 small-scale community-run ASR systems have previously been implemented in coastal areas for drinking water security purposes (Naus *et al.*, 2021). However, only a few systems have been implemented for agricultural water supply. Agriculture in coastal Bangladesh, however, faces major challenges including the issue of salinity, which restricts farmers to one or two rain-fed crop harvests per year (Rolf *et al.*, 2019).

Project overview

In 2019, to ensure dry season irrigation, farmers in Dacope of Khulna, Bangladesh, installed an ASR system with the help of a local, non-governmental organization (NGO). The system (Figure 1) consists of a three-metre-deep infiltration chamber and a 50-metre-deep borehole with a ten centimetre diameter. The chamber is filled with filtration materials which are arranged to promote safe, groundwater recharge (replenishment) of impure floodwater. During the dry season, this type of managed aquifer recharge (MAR) system can irrigate an area of approximately four hectares.

The aim of the technology was to reduce the salinity of groundwater and enhance agricultural productivity at the study site. Several studies have been conducted to

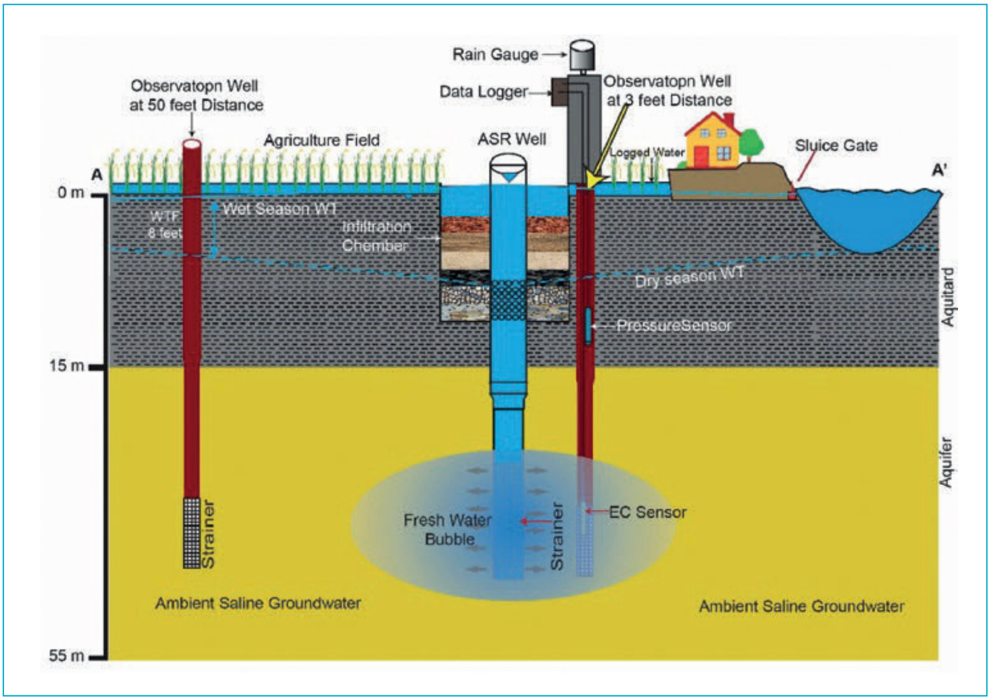


Figure 1: Diagram of an Aquifer Storage and Recovery (ASR) system (WT = water table)

assess the feasibility and health risks of ASR systems with regards potable water, but fewer studies have been conducted on the performance, health risks and feasibility of ASR in agriculture.

This case study aims to determine the efficacy of the ASR system in the agriculture sector and assess the potential health hazards of aquifer contamination.

Team

The collaborative team included researchers and partners from the Bangladesh University of Engineering and Technology; the Bangladesh Agricultural Development Corporation; and the Krishi Gobeshona Foundation, Bangladesh.

Method

The study used socio-technical methods in its investigation. The social component consisted of four focus-group discussions to generate resource maps and crop calendars, and compare changes in crop patterns and intensity over the ASR implementation period. The technological component involved real-time in-situ observations as follows:

1. Pressure sensor to measure groundwater level;
2. Rain gauge (tipping bucket) to record rainfall;
3. Electric conductivity (EC) to measure salinity;
4. Temperature sensors to measure temperature.

Automated logging devices were installed at an observation well, one metre from the ASR. Additionally, EC was manually measured in logged surface water, neighbouring canal water and at an additional 50-metre-deep observation well situated 15 metres from the ASR well. Readings were taken every 15 days using an EC meter.

Water samples were collected from both the ASR and the observation wells, as well as logged surface water and canal water, during four specific seasons: pre-monsoon, monsoon, post-monsoon and dry periods. The purpose of this collection was to monitor the contamination levels of coliform (faecal matter), as well as other water quality parameters including alkalinity, water hardness, iron, manganese, Total Dissolved Solid (TDS) and turbidity (the level of particles present in the water, such as sediment or organic by-products).

Chemical tests were performed as follows:

1. Alkalinity and hardness were tested using the titrimetric method (to assess concentration);
2. Coliform was assessed using the Membrane Filtered Method (a separation technique that utilizes a semi-permeable membrane to halt solids and dissolved components);
3. A turbidity meter was employed to analyse TDS;
4. Iron and manganese elements were analysed using the Atomic Absorption Spectroscopic method, which detects elements in liquid samples through electromagnetic radiation analysis (i.e. identifying elements by the way they absorb wavelengths).

Google Earth Engine was used to collect cloud-free satellite images prior and subsequent to ASR installation. The images were then compared to assess changes in land use and land cover (LULC) over the study period. The analysis was conducted during the dry season (January to April) when farmers typically use ASR water.

This study classified LULC using spectral bands (different ranges of wavelengths of light captured by satellite sensors) and estimated the extent of farmland in the study area using the Random Forest (RF) algorithm – a computational method in which land cover is constructed from existing data via machine learning. The team chose RF since it classifies remote sensing data more accurately than other methods (Belgiu and Drăguţ, 2016).

Results and products

Land use and land cover

Prior to the introduction of ASR (2018), farmers cultivated vegetables and watermelons in the dry season, or kept their land uncultivated. By 2022, after ASR implementation, the northern, western and eastern areas of the study area had undergone a transition from fallow to agricultural use, specifically rice cultivation (Figure 2a).

Figure 2b illustrates the increase in the agricultural area over the designated timeframe. Farmers who received the ASR system and employed it as an alternative irrigation water source, encountered notable benefits. The production of Boro rice, for example, increased from three to almost five tons per hectare.

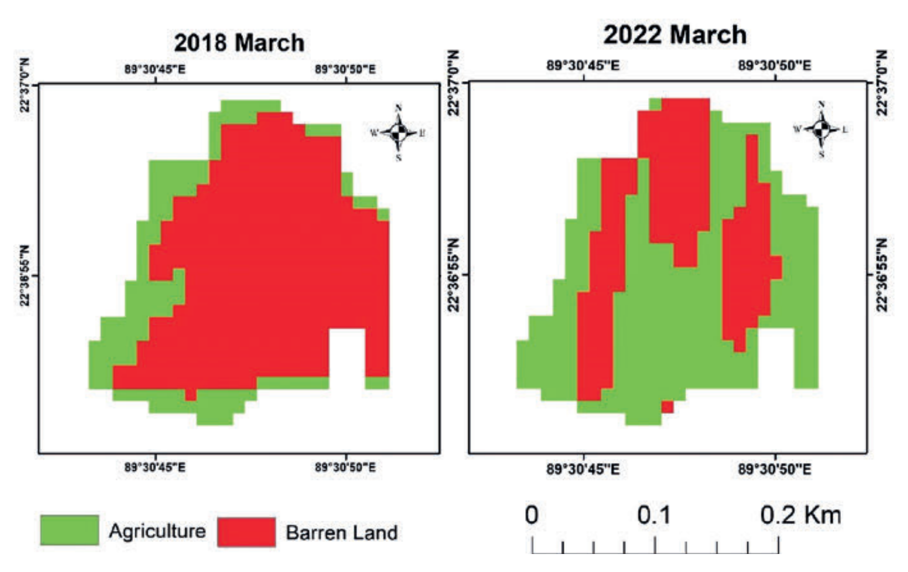
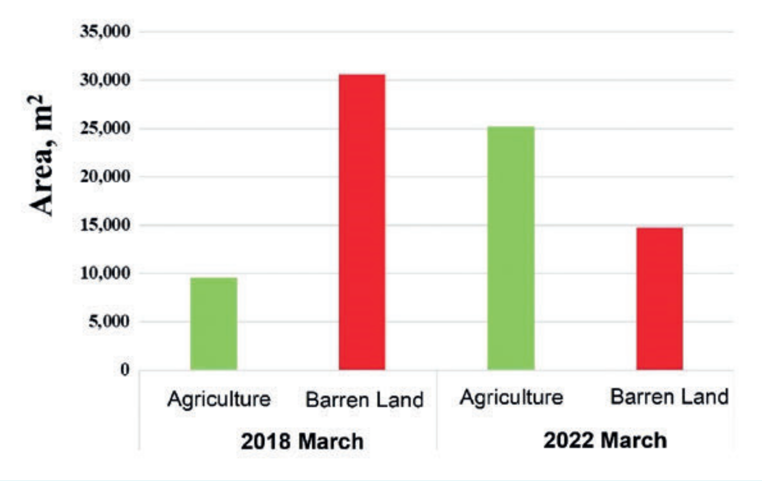


Figure 2: (a) Land use change before and after ASR implementation

Figure 2b: Increase in agricultural area after ASR implementation between 2018 and 2022



Water levels

Groundwater levels showed a direct correlation with rainfall events (Figure 3), with rapid increases in levels from pre-monsoon to early monsoon (May to July). However, after July, when the aquifer had reached saturation, there was only a minimal rise in the groundwater level despite heavy monsoon rainfall.

From July to November, the groundwater level continued to rise, if slowly, through to October despite the absence of significant rainfall. Tropical cyclone *Sitrang*, caused notable rainfall at the end of October (Figure 3a), recording 209 millimetres of rain in 24-hours and a subsequent rise in the groundwater level of 0.3 metres, which gradually returned to its initial position after five days.

The presence of a 'mound formation' inside the water table of the ASR system, in comparison to the surrounding ambient observation wells, suggested the occurrence of surface/rainwater percolation (movement through the soil) and subsequent recharge of groundwater.

In brief, the data suggests that ASR in coastal regions of Bangladesh can serve as an effective means of recharging groundwater, although its impact diminishes significantly when the aquifer becomes saturated during monsoon.

Salinity

There were similar fluctuations in the EC (salinity) data. When the land was waterlogged, for example, conductivity in the ASR dropped from 6,300 microsiemens per

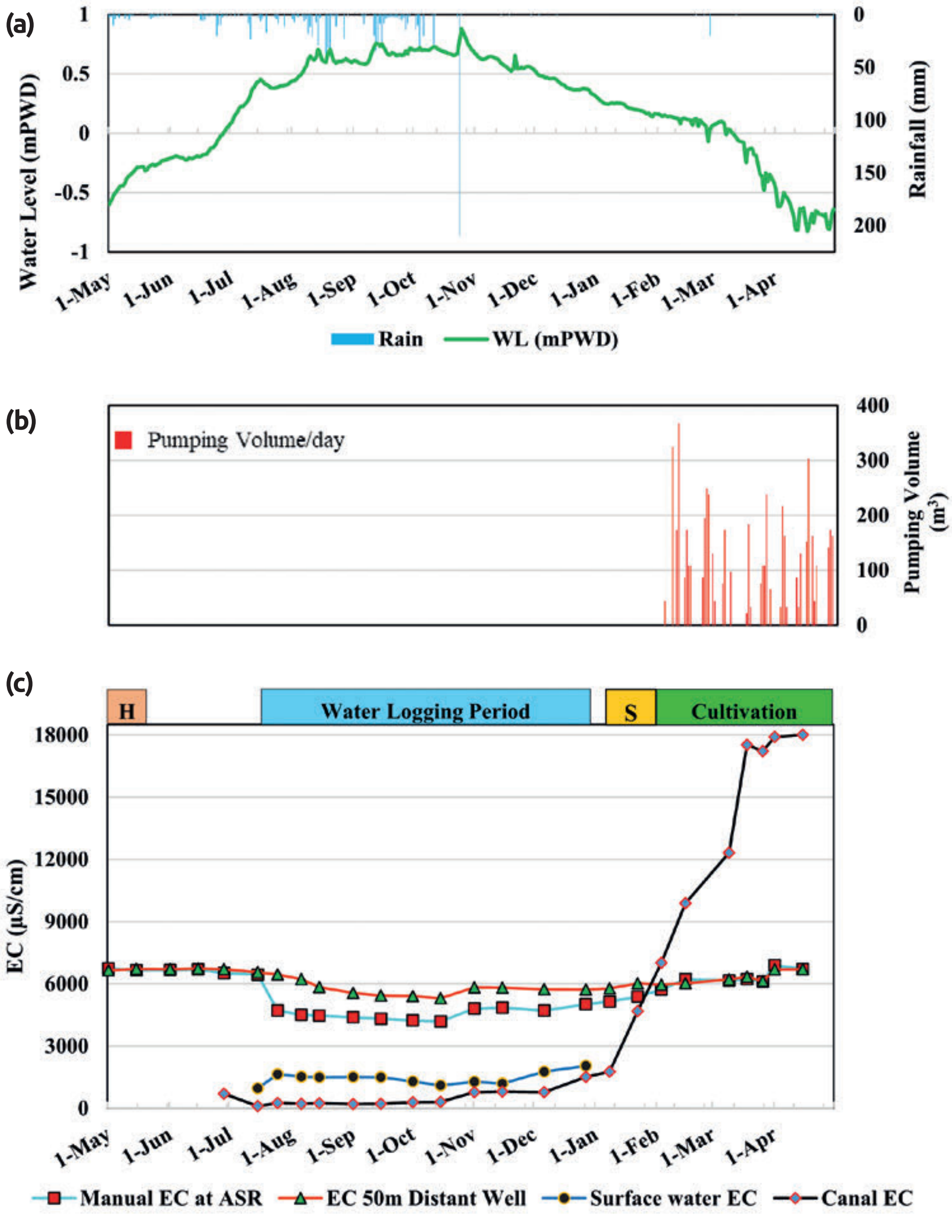


Figure 3: (a) Water level change in response to rainfall, (b) abstraction volume (cubic metres per day) from ASR well, (c) EC change in different sources of water at the ASR site

centimetre to between 4,100 and 4,850 microsiemens per centimetre (Figure 3c) indicating lower salinity. After waterlogging receded, the EC in the ASR exhibited a small increase in comparison to the neighbouring observation well. But after 367 cubic metres of irrigation water were pumped in February (Figure 3b), the EC went back to its original measurement (the same as the EC of ambient groundwater). This implied that freshwater recharge via ASR had limited impact on reducing salinity.

Water quality

Bangladesh standard limits (BSL) were used as the standard metric in all the following results (visualized in Figure 4). However, there is no BSL for alkalinity.

Alkalinity: the ASR system exhibited higher alkalinity in comparison to the logged surface water and canal water. This suggests ASR water underwent more rock-water interactions than the other water sources.

Water hardness: logged surface water with low hardness (below BSL), exhibited high hardness when percolated. This is similar to neighbouring observation wells and indicates good mixing with the aquifer.

Coliforms: total coliforms (including bacteria) were detected throughout the year in various water samples. In the ASR well, their absence was only observed after clogging clearance had been performed. Faecal coliforms were consistently present in canal water and logged surface water. This suggests that a successfully functioning ASR filtration chamber can effectively eliminate coliforms from surface water sources.

Manganese: manganese was frequently observed at elevated levels (above BSL) with the greatest concentrations occurring in September for groundwater and logged surface water, and in February for canal water.

Iron: elevated iron levels (above BSL) were found throughout all instances, with the exclusion of two (November and July).

Total dissolved solids (TDS): TDS in groundwater consistently exceeded the BSL whereas levels in logged surface water remained within limits. Canal water exhibited the largest peaks, exceeding 15,000 parts per million.

Turbitidy: All the water samples, including the ASR well, showed increased levels of turbidity (sediment or organic by-products).

In brief, the coexistence of higher concentrations of iron, TDS and turbidity, collectively, signifies the likelihood of well clogging within the ASR system.

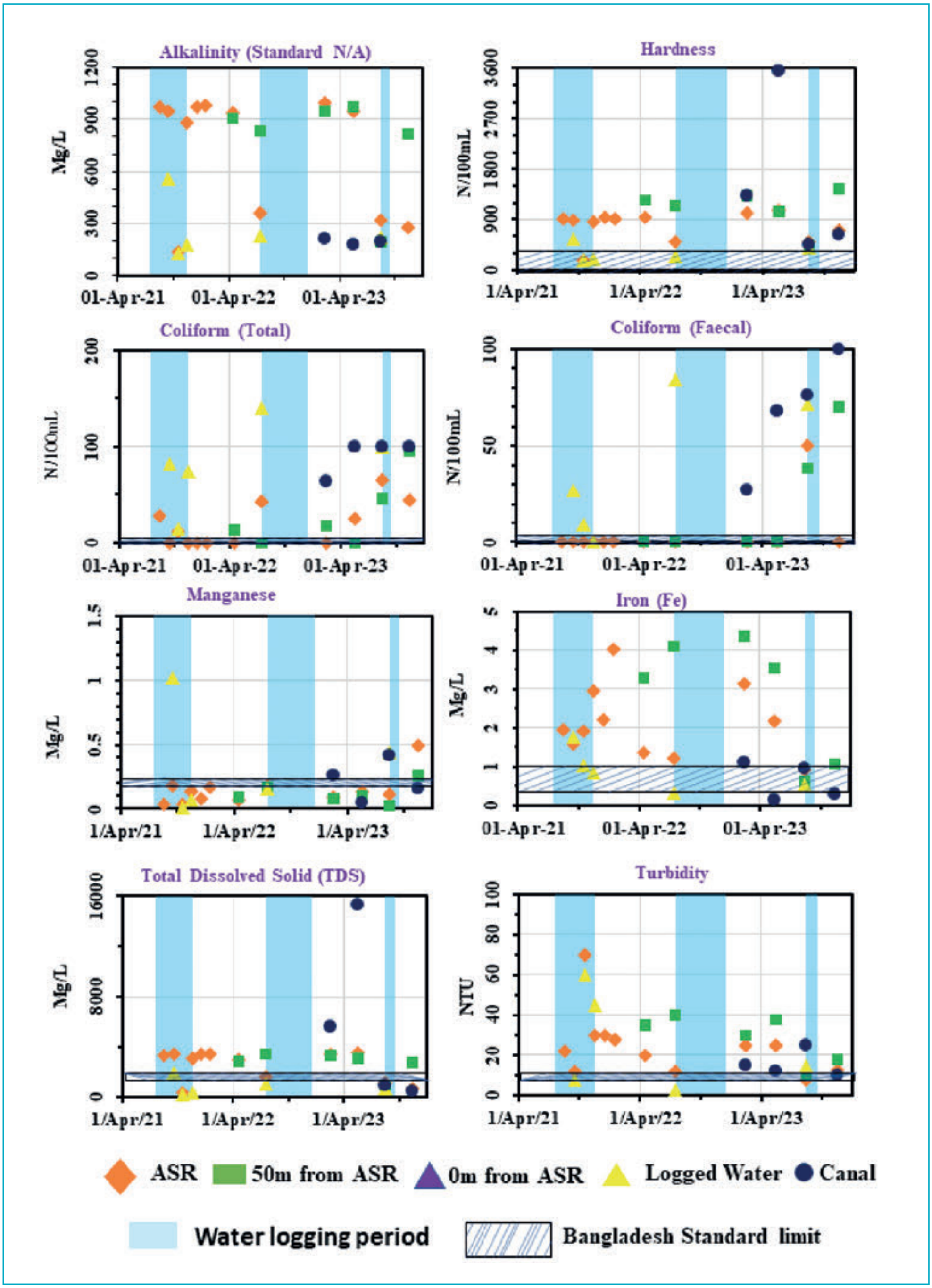


Figure 4: Different water quality parameters at ASR-Agri-MAR study site

End-users

This research is intended for policy makers such as the Ministry of Water Resources (MoWR) and the Bangladesh Ministry of Agriculture (MoA). Also, government entities such as the Water Resources Planning Organization (WARPO) and the Bangladesh Agricultural Development Corporation (BADC). As a collaborative partner, the BADC will disseminate research findings to relevant institutions.

At a local level, the NGO and the farmer who implemented the ASR system, serve as principal stakeholders and recipients of the study's outputs. Many more farmers have expressed an interest in ASR and more NGOs are keen to sponsor ASR services to farmers in exchange for a fee.

Lessons learned

1. ASR has the potential to reduce local saline levels against the backdrop of climate change stress. Early rainfall events and monsoon water have been found to have a beneficial effect on the groundwater recovery of ASR systems, as well as reducing local saline levels. ASR helped increase the production of dry rice and benefited farmers by enhancing cropping intensity and agricultural land use within the ASR catchment area.

2. Small-scale, single ASR chambers (1.2 x 1.2 x 3 cubic metres) have the capacity to deliver 367 cubic metres of mix-water before reaching equilibrium with ambient saline groundwater. Therefore, it is not feasible for a single ASR system to meet the irrigation needs of water-intensive Boro rice over the dry season. However, ASR can be used effectively for growing various non-rice crops such as vegetables and watermelon.

3. ASR systems successfully prevent the transfer of faecal coliform pollution into the aquifer. Water quality overall is acceptable but turbidity, iron, and TDS are beyond permissible limits and suggest ASR systems might face ongoing clogging issues. Frequent clogging removal is crucial.

4. ASR systems appear to be inadequate for meeting sustainable, all-year-round demand for freshwater irrigation in coastal regions. The feasibility of extending a single filtering chamber and/or using multiple ASR chambers needs to be evaluated, paying particular attention to economic viability.

5. While ASR is a promising strategy for tackling saline water challenges, other approaches could be incorporated. For instance, substituting rice with higher-value crops such as watermelon. ASR technology could also be used in conjunction with other water filtration devices such as Pond Sand Filters (PSF).

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