



# **Underground fresh water storage**

A practical solution to  
increase water security in  
saline deltas

# Acknowledgement

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# Foreword

Bangladesh has made steady progress towards Millennium Development Goal 7 of halving, by 2015, the proportion of the population without sustainable access to safe drinking water. However, ensuring safe drinking water remains an issue, particularly for the most vulnerable and those living in remote and hard-to-reach areas.

Along the coast of Bangladesh, many inhabitants suffer from acute water shortages as groundwater from both the shallow and deep aquifers is saline, there is almost no rainfall for seven months of the year, and fresh water reserves are contaminated during storm surges. To compound matters further, many existing water sources are heavily contaminated with bacteria. As a result, much of the population in coastal regions cannot collect drinking water from an improved source within 150 metres of their household throughout the year which meets national drinking water standards.

With funding from the Embassy of the Kingdom of the Netherlands, UNICEF in collaboration with the Department of Public Health Engineering, University of Dhaka (Department of Geology), Acacia Water and national partners piloted and then scaled up application of the Managed Aquifer Recharge (MAR) approach in Bangladesh.

This innovative technique, which collects rainwater and fresh pond water and then stores it in shallow groundwater aquifers, provides communities in coastal Bangladesh with year-round access to a sustainable source of safe drinking water that is resilient to disasters and the potential impact of climate change. In addition to coastal areas, MAR systems were also piloted at research sites to assess the suitability of the technique to supply

safe water in arsenic-affected areas and to enhance groundwater recharge in urban settings. The results from this initiative provide sector partners with a comprehensive set of tools to implement MAR systems at scale in Bangladesh.

We hope that sector partners, including planners, policy makers, donor agencies and those in the private sector will strongly consider MAR systems as a water supply option in appropriate areas. Implementation of sustainable, cost-effective solutions is necessary to improve the lives of the most vulnerable, including women and children of Bangladesh.

Pascal Villeneuve  
Representative  
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# 1 A global issue

## fresh water scarcity in saline deltas

Coastal regions are among the most densely populated areas in the world, with large cities and vast agricultural areas. Therefore, many of these regions require a substantial amount of fresh water for drinking, domestic needs, agriculture and freshwater dependent industries. Fulfilling this demand can be challenging, especially in areas with a pronounced dry period. In some coastal areas groundwater provides a reliable source of fresh water. However, in many deltas the groundwater is saline or polluted and not suitable as drinking water. Here people often depend on surface water for their water supply during the dry period, which may lead to health risks, as surface water is vulnerable to pollution and diseases.

Fresh water sources may become even more stressed in the future. Fresh groundwater resources can get exhausted when the abstraction levels exceed the recharge, for example in large cities with high abstraction rates (such as Dhaka) or in areas where the infiltration is limited. Additionally, population growth and/or economic development can increase water demand, particularly in coastal areas of the world. Furthermore, climate change may result in sea-level rise, intensify drought periods, and increase the frequency of cyclones, thus impacting the quantity and quality of fresh water supplies.

One of the most vulnerable areas is the south-western coast of Bangladesh, where a few million people suffer from severe water scarcity. Here the groundwater is mostly brackish to saline or has unsafe concentrations of arsenic. As a result, many people use surface water from ponds or rivers which are often contaminated and turn brackish or salty over the course of the dry season. Fresh water scarcity in this region becomes extremely severe after the cyclonic storms which hit the coastal region regularly.

For example, after cyclones Sidr and Aila which hit Bangladesh in 2007 and 2009, respectively, most of the fresh water sources were impacted and water had to be imported to the affected areas from long distances.

In addition to Bangladesh, populations in other deltas in Asia experience similar challenges in securing safe water supplies due to the presence of saline or otherwise polluted water sources and the risk of natural disasters. For example, in Vietnam rainfall is decreasing, sea levels are rising and salt water is migrating further inland along the Mekong Delta, threatening fresh water supplies in this area.



Photo 1. Collection of drinking water during flood events.



Photo 3. Watervending by boat in the saline delta region.



Photo 2. Watervending in case of drinking water scarcity.



Photo 4. Collection of drinking water in the saline delta of Bangladesh.





# 2 A practical solution

## MAR systems

### 2.1 | What is underground fresh water storage?

In Bangladesh the Managed Aquifer Recharge (MAR) concept was implemented as a solution that provides communities with access to year-round, sustainable safe drinking water. This model can serve as an inspiration for fresh water supply in the region and worldwide, for coastal areas that suffer from a scarcity of safe drinking water.

Capturing and storing water can be a solution to provide fresh water in periods when it is normally scarce, thus increasing the resilience to droughts. In many regions where people suffer from water scarcity, the actual yearly rainfall is more than enough to fulfill the demand. However, the rainfall is not distributed equally over the year. During the monsoon, large amounts of water fall within a relatively short period, while in the dry period fresh water is scarce. The lack of clean, fresh water -now or in the future- could be solved by storing water when it is abundant (e.g. during the raining season) and making it accessible in a safe manner when it is required throughout the year.

An excellent option is to capture fresh water and store it underground, where it is protected from pollution and is further purified as it flows through the aquifer. Such underground fresh water storage can be realized at locations where the groundwater is originally brackish by the creation of an underground 'fresh water bubble' within the aquifer. The approach is

most commonly known as MAR but is also referred to as Aquifer Storage and Recovery (ASR) and Groundwater Buffering.

### 2.2 | How MAR systems work

When MAR systems are applied at locations where a sandy aquifer extends to ground surface, only a pond or basin is required to infiltrate fresh water directly into the ground. Alternatively, MAR systems can also be applied at locations where a clay layer exists on top of the aquifer. At these locations, vertical wells are required to actively infiltrate the fresh water into the aquifer. Conditions in the coastal plain of Bangladesh are the latter, with a clayey layer above the aquifer. Therefore, the MAR systems that have been applied in Bangladesh use vertical infiltration wells.

For MAR systems, fresh water is collected from rooftops and/or ponds (figure 1.a). The collected water is passed through a sand filter, and infiltrated into the ground with four infiltration wells (figure 1.b), where it creates a fresh water bubble in the saline aquifer. The fresh water bubble stays intact underground, because the water mixes only at its very edges with the surrounding saline water. When fresh water is required it can be abstracted from the bubble with a hand pump (figure 1.c). The MAR system is thus making safe water available when it is required.



# MAR system: Managed Aquifer Recharge

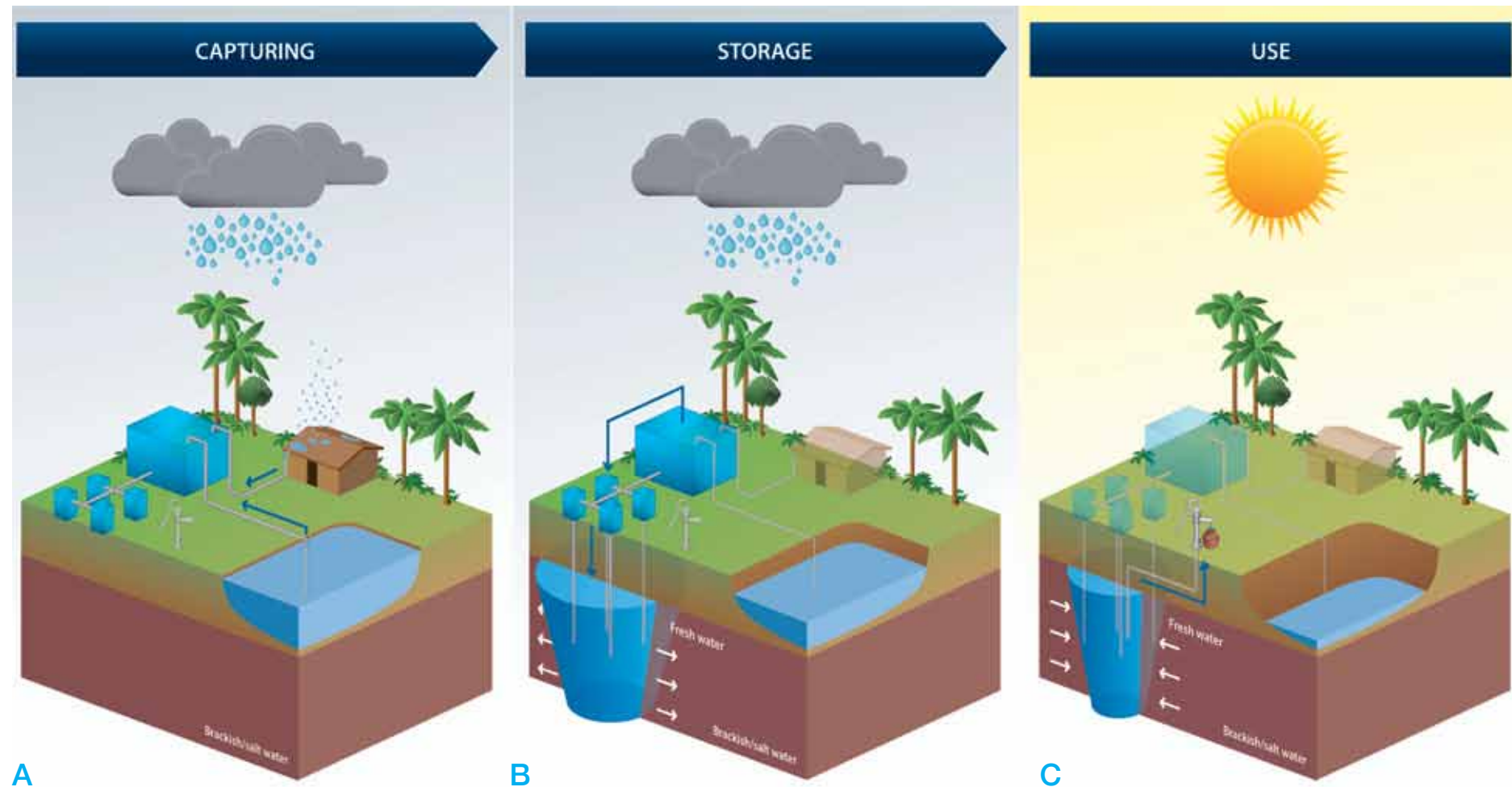


Figure 1. The MAR system in the three phases of capturing, storing and use of fresh water.

## 2.3 | MAR systems a promising solution of ‘proven’ concept

The concept of underground fresh water storage in a saline environment has been applied in many countries and is a reliable, proven solution. For example, in the Netherlands sand dunes are used for drinking water storage and purification. Here, river and rain water is infiltrated into the dunes to create extended underground fresh water bubbles that ‘float’ on the saline groundwater. The fresh water is used to supply cities such as Amsterdam with high quality water.

A comparable system of artificial recharge in dunes is also applied in South-Africa. In addition to rainwater, here the run-off from urbanized areas is also captured and infiltrated. In this manner enough water can be stored during the wet period to supply the city of Atlantis with good quality drinking water throughout the duration of the dry season.

On a smaller scale, MAR systems have been used by individual farmers in the coastal plain of the Netherlands. These systems capture water from greenhouses and infiltrated into the ground under the clay layer with vertical wells. Here, the application of the MAR systems saves space above ground compared to surface water storage while ensuring a year-round supply of high quality water required for irrigation of crops.

In Bangladesh, a number of MAR systems were built, as detailed in chapter 3. These systems are innovative, low cost and tailor-made for drinking water supply for the rural communities in the coastal plain.



Photo 5. River water infiltration in sand dunes for drinking water, The Netherlands.



Photo 6. Fresh water infiltration under de clay layer for agricultural use.



## 2.4 | Advantages of underground fresh water storage

MAR systems provide numerous advantages compared to traditional water supply options, which make them attractive solutions for the safe fresh water supply, under the right conditions. Here an overview is provided of the general advantages of the application of the MAR system for the local, rural scale:



### Improved year-round water availability

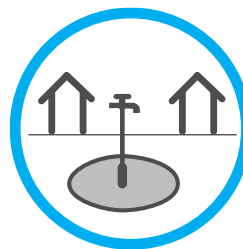
Fresh water can be collected and stored when it is abundant, for example during the monsoon, and during dry periods. This is a particularly important advantage in areas with a pronounced dry season. Thus, MAR systems increase the amount of fresh water that is available throughout the year.



### Improved water quality and reduced health risks

Because MAR systems provide a water buffer by storing water underground, water does not have to be infiltrated throughout the year. Therefore, water can be infiltrated at specific time when the quality is best, thus storing only relatively high quality water. Furthermore, the advantage of groundwater storage is that it is largely protected from external pollution.

The underground storage has therefore a low risk of contamination from water borne diseases. Also, the microbiological quality of MAR water is improved in comparison to surface water by the residence in the aquifer.



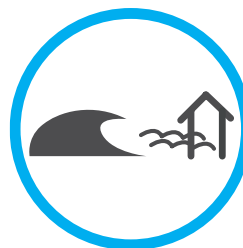
### Suitable for local-scale application

MAR systems can be applied at the scale of a small village, while also larger scale applications are possible (see e.g., paragraph 2.5.). The small scale application provides the opportunity to apply the MAR technique for rural communities, and construct systems relatively close to the users. MAR systems also have limited complexity and operation and maintenance requirements. The systems can be operated by local users, and maintained by locally-trained technicians.



### Cost-effective

The costs for MAR systems are competitive to the cost of other fresh water solutions that provide year-round safe water (see chapter 3.3) in areas with saline groundwater, such as rainwater harvesting, reverse osmosis and water supply by a water vendor. MAR systems thus provide a cost effective solution in coastal areas.



### Resilient to disasters

The underground stored fresh water is protected from cyclones and the floods that often hit coastal regions. The fresh water bubble is protected by the clay layer and is not polluted when the area is flooded with saline and/or contaminated surface water. Also the hardware can be designed to withstand natural disasters, making the MAR system resilient in cyclone and flood prone areas. Collection and (underground) storage of surface water during peak events can also manage flood-water. Especially in cities and other areas with relative limited water storage opportunities, artificial infiltration into the ground, e.g. of water captured from the rooftops, can help to reduce peak flow.



# 3 The Unicef Bangladesh project

## Fresh water storage for drinking water

### 3.1 | Introduction

UNICEF is committed to providing rural communities with access to safe, sustainable drinking water with local scaled solutions. Dhaka University and Acacia Water share this intention and, in cooperation with the Department of Public Health Engineering (DPHE) and local NGOs, started an action research project, to face the challenges of water scarcity in coastal Bangladesh. The MAR-UNICEF project. With funding provided by the Embassy of the Kingdom of the Netherlands, 100 MAR systems are scheduled to be constructed in Bangladesh by the end of 2014. These systems were specifically designed to provide rural communities in the coastal plain of Bangladesh with year-round access to safe drinking water.

Though the MAR technology is not new, the current application of MAR systems in this project is rather unique. These systems are developed to be low-cost and low-maintenance, constructed using local materials and labor where possible, and to be robust in this disaster-prone region. The systems are applied at a small scale, while there is the potential to replicate these systems to create a sustainable water supply for larger population in the coastal plain. This approach is in line with the policy of the national government to ensure sustainable and safe fresh water for all sectors, with a focus on local scale solutions. For further details behind the information in this chapter see the technical reports (TR), referred to in chapter 6.

### 3.2 | Learning from piloting

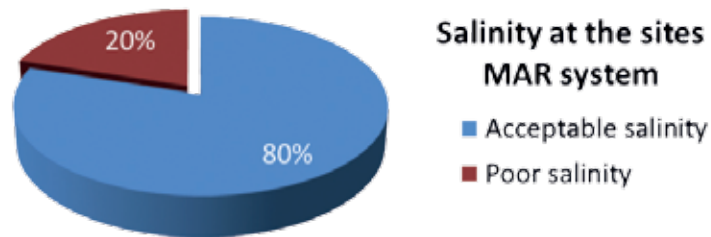
The process started by preparing optimal MAR system designs, and then piloting the designs to assess their feasibility locally, with and within the community. During the process it was demonstrated that construction is possible with the use of local experience, technologies and materials. The process of learning by doing provided new insights in the design, feasibility and environmental requirements for MAR systems in coastal Bangladesh. Further details on this process can be found in TR4. These systems were shown to be a solution which can provide sustainable, safe drinking water throughout the year to support public health.

The MAR-UNICEF project started with the construction of 20 schemes in the Shatkira, Khulna and Bathiagati Districts in 2009 – 2012. The purpose of piloting these first 20 schemes was to design, test and improve the MAR system. The first schemes were proven successful, with an average total storage of approximately 900 m<sup>3</sup> of fresh water per year at each location. This volume will provide 250-300 people with 15 litres of safe drinking water for 200-240 days. This is more than the actual per capita use of 3-6 L/day (see figure 2).

Important action research questions which were investigated during monitoring of the first schemes from 2012 to 2014 were the sustainability of the infiltration rate and the percentage of the infiltrated water than can be retrieved again from the fresh water bubble (i.e., the recovery efficiency). The results led to a cost neutral improvement of refining the infiltration well design, shifting infiltration from gravel-filled wells to hollow 4" wells



that are surrounded by gravel. This strongly increased the infiltration rate to provide a theoretical supply to at least 300 people under the current system design. Further information on the efficiency of the systems will become available as the systems are in full use and monitored over the coming years.



Results from water quality monitoring of the MAR systems that were constructed as pilots are:

- The salinity decreased to acceptable limits at 16 out of 20 sites;
- The iron concentration reduced significantly at all sites;
- The presence of arsenic reduced at most sites,
- The microbiological quality of the groundwater was improved compared to pond water.

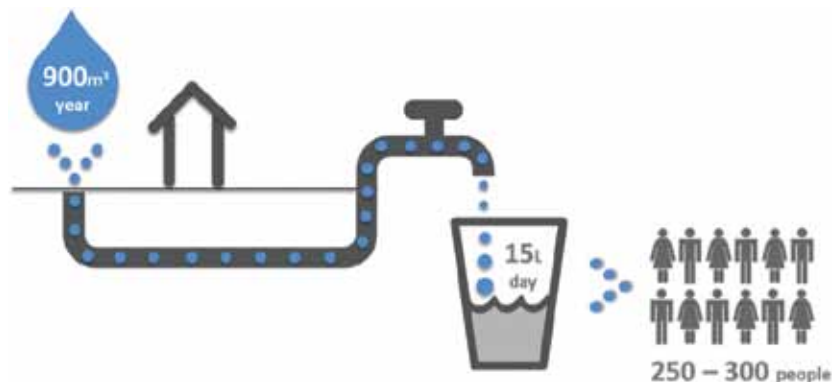


Figure 2. Infiltration of 900 m<sup>3</sup> water in a year, could provide approximately 250-300 people with 15 litre of drinking water a day.



Photo 7. Above ground MAR system.

Based on the first piloting phase, the MAR design was finalized. Under this design, water infiltrates into the ground under direct gravity through infiltration wells (see figure 1). The fresh water source is pond water which can be combined with rooftop rainwater, if it is available. In the selected design, four infiltration wells are placed in a square, mutually creating a fresh water bubble, from which drinking water is abstracted with a hand pump that is placed in the middle.



Photo 8. Underground MAR system.

### 3.3 | Costs of the MAR system

The MAR systems were applied in an innovative way: at a small scale and tailor made for the community. The systems were constructed with local labor and materials from within the district and division, and the full maintenance can be done by trained locals. This resulted in a low-cost approach for underground fresh water storage.

The MAR systems were found to be cost effective compared to other fresh water solutions in areas with saline groundwater, including reversed osmosis (RO), rainwater harvesting (RHS) in plastic or concrete basins, or water delivery from local fresh water sources by water vendors. The financial differences are based on the construction costs, the costs of operation and maintenance, the life expectancy of the system, the number of consumers per system/unit and the total volume of water supplied by each intervention. Pond Sand Filters (PSFs) can provide fresh water at lower cost, but these systems appear to have a low level of acceptance given the high percentage of non-functioning PSFs in the rural area of Bangladesh. The main reasons for not using PSFs are reported to be (i) the time required for water collection, (ii) limited functionality due to lack of maintenance, and (iii) the low awareness about health risks of using pond water. Furthermore, the ponds that provide water for PSFs become saline during cyclones and storm surges.

In areas on the coastal plain with sufficient fresh groundwater, MAR systems are less competitive. Here, water from hand pump tube wells or piped water supply from large diameter wells are found to be cheaper. In these areas MAR systems appear only attractive if the groundwater is depleted due to over abstraction.

Therefore, at locations where the groundwater is saline, or where the groundwater could be depleted, MAR systems are a financially attractive option. In follow-up research, options to further optimize the cost effectiveness of MAR systems will be explored, for example, by the application at a larger scale. Details on the financial and economic evaluation of MAR systems can be found in TR2.

### 3.4 | Upscaling of MAR systems

It is estimated that more than one million people in the coastal districts of Bagerhat, Khulna and Satkhira require access to safe drinking water. To achieve this goal, upscaling of the MAR systems is required. Therefore, with the knowledge and experience gained during the 20 pilots, upscaling started in the period of 2013–2014 with construction of an additional 75 MAR systems. Further details on the upscaling see TR6.

A detailed feasibility survey was carried out for the site selection, in which in total of 330 potential sites were studied. The findings of the site selection were analysed with spatial data in a GIS platform to create a 'MAR feasibility map' for the three target districts. The results combined areas with a high physical potential for the application of MAR systems (map 1) and the areas with a high demand for fresh water to identify areas with the highest priority (map 2). The maps are based on the aquifer characteristics and the salinity of the groundwater, the population density, land use and the presence of deep or shallow tube wells. For further details see TR1.



## 3.5 | Longterm operation: socio-economic aspects

The challenge is to manage MAR systems in such a way that the process of construction, operation and maintenance is conducted in a sustainable manner. The feasibility improves when the management structure is adapted to the local demand, the institutional environment, and the local technical abilities. For the full acceptance of MAR systems as a safe water source a clear communication and the involvement of the local community from the start of the project is recommended.

In the MAR-UNICEF project different management and ownership structures are being explored. An example is the management structure where a Water User Association is appointed as the owner of the system. They appoint the key players, which are the care-taker, the technical supervisor and the village user committee. The care-taker maintains and operates the system on a daily basis and the technical supervisor visits the site once a week, together they are responsible for the water safety implementation. Finally, the user committee is responsible for the community mobilization and the financial assurance. Optionally, DPHE, a local NGO, or private operator can join the management structure.

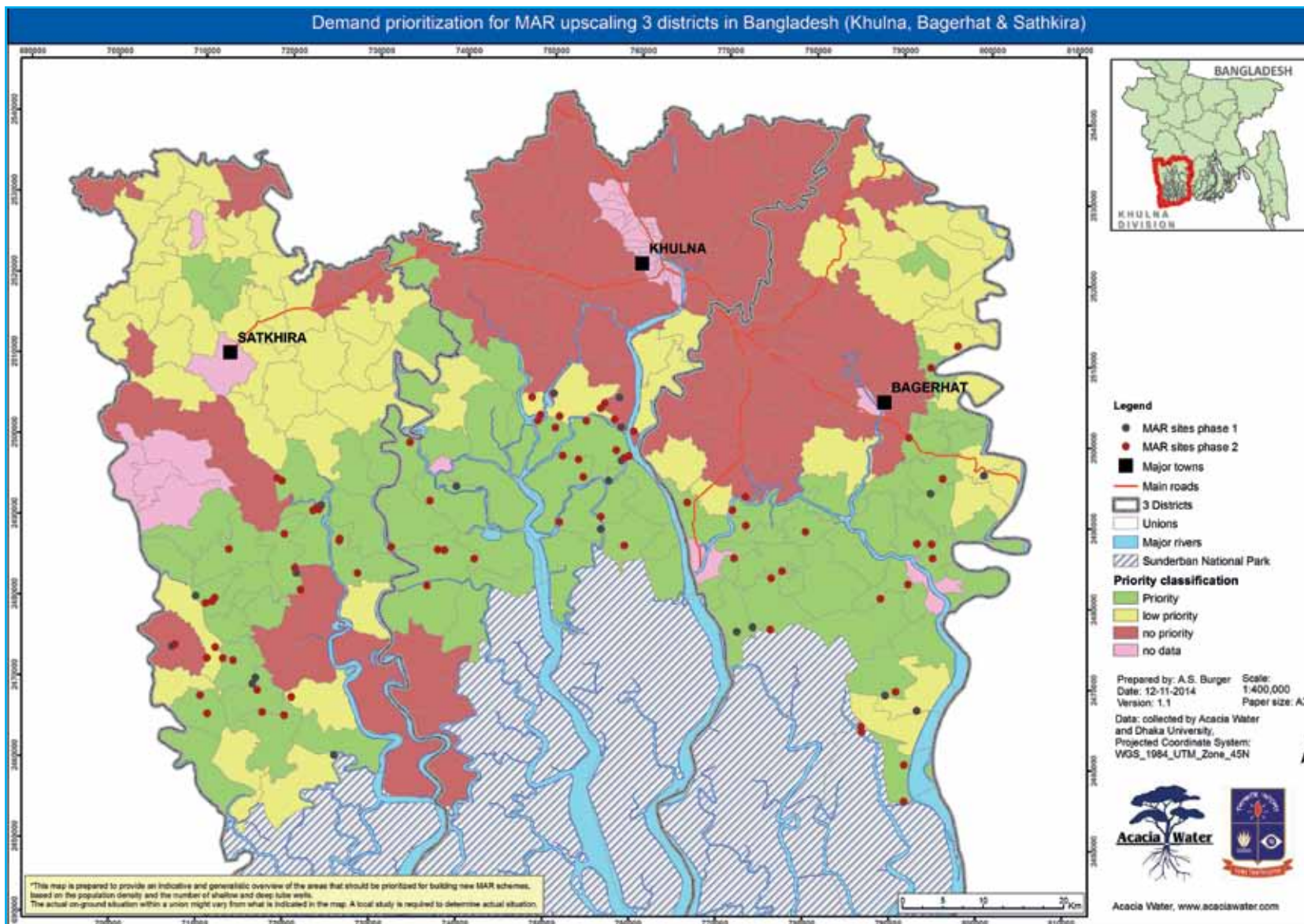
Smart planning of the MAR systems can reduce the operation and maintenance costs, for example by placing a number of schemes in one village. Both the caretaker and the supervisor can take several schemes under their responsibility. Being responsible for different schemes ensures that knowledge and experience can be applied more broadly, thereby reducing the total costs. In addition, it will provide a good opportunity to secure operation and maintenance at an affordable cost. Further details on the social assessment study and Water Safety Plan can be found in TR3 and TR5.



Photo 9. MAR system users in the south-western coast area of Bangladesh.

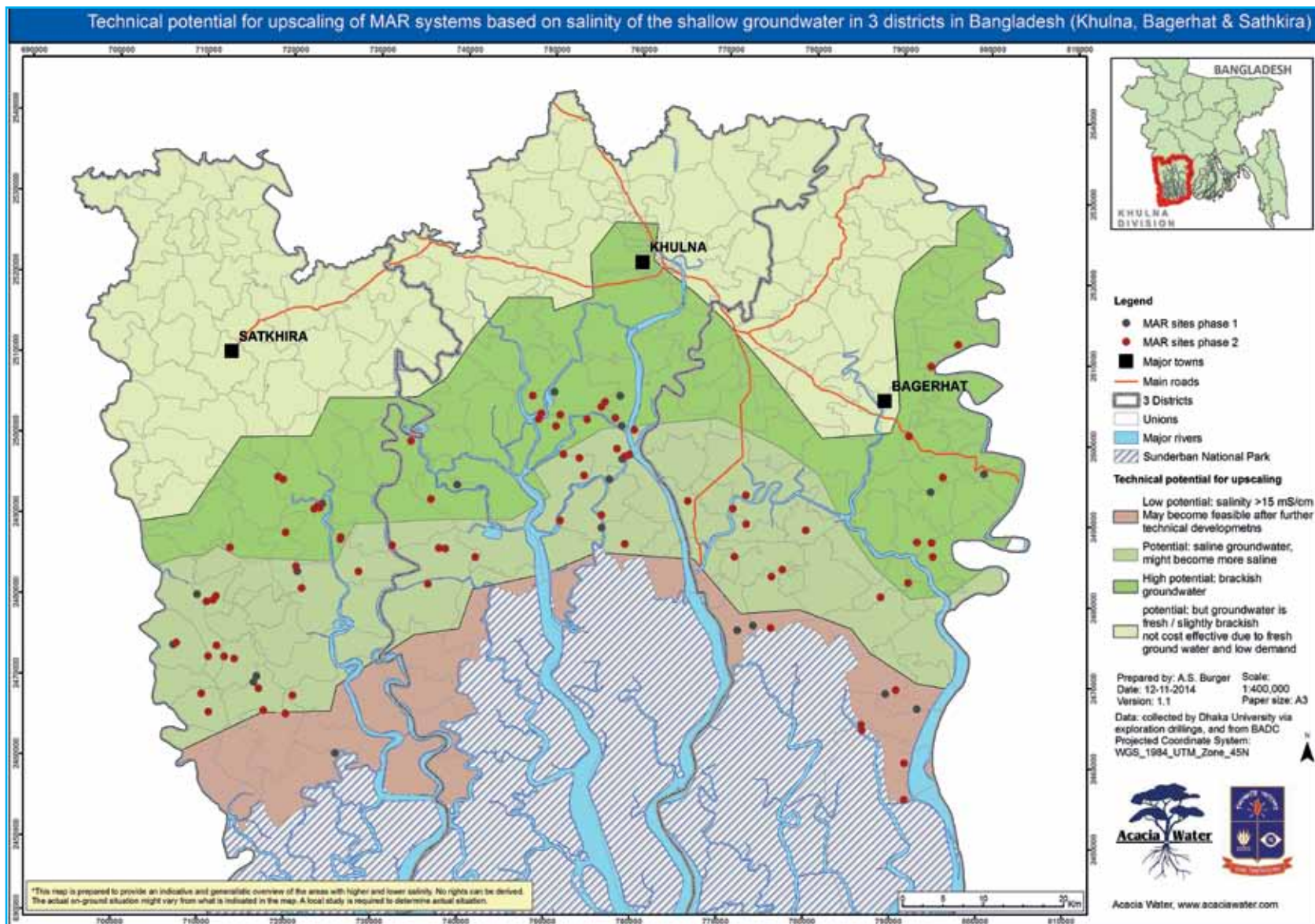


Photo 10. Underground MAR system in front of the pond.



**Map 1. Demand prioritization for MAR upscaling:** The demand prioritization map is based on population density and the presence of shallow and deep tube wells. An analysis with these parameters result in a prioritization map with three classes; no priority, low priority and priority for MAR upscaling in the districts of Khulna, Bagerhat and Sathkira. The prioritization map is prepared to provide an indicative and generalistic overview. The actual on-ground situation within a union might vary from what is indicated in the map. A local study is always required to determine the actual situation.





**Map 2. Technical upscaling:** Based on the salinity of the shallow groundwater, a technical potential map for upscaling of MAR systems is prepared. The results are presented in a range of high and low potential. This map is prepared to provide an indicative and generalistic overview. The actual on-ground situation within a union might vary from the map. A local study is always required to determine the actual situation. Besides, the dynamic character of technical development permits changing potential in the future.



# 4 Spin-off projects: in Bangladesh and cross-country

The MAR systems implemented in the coastal area of Bangladesh, under the current MAR -UNICEF project, have already led to a number of spin-off projects in Bangladesh and abroad. In this chapter some important examples of those spin-offs are highlighted.

## 4.1 | Follow-up on the current systems

Action research on the 100 systems that will be implemented by the end of 2014 will continue in a follow-up project in Bangladesh: the Delta-MAR project, which is funded by the Urbanizing Deltas of the World (UDW) program. In this project the hydrological, geological and chemical prerequisites for the successful application of MAR systems will be explored in more detail, providing a model that predicts the expected MAR performance at a specific location based on a few, easily measured parameters. The MAR governance will also be analyzed and the business cases for the regional MAR implementation will be developed further. Finally, the project will elaborate on the potential for MAR systems, adding detail to the current potential map and extending it towards the full saline delta in Bangladesh and to similar delta's worldwide, taking into account the lessons of the MAR-UNICEF project (TR8). The project consortium includes four universities (VU University Amsterdam, Utrecht University, Delft University of Technology, University of Dhaka), the local government (DPHE), UNICEF, NGOs (SIMAVI), and a consulting company (Acacia Water)<sup>9</sup>.

## 4.2 | Replication in Bangladesh under this project

### MAR system for groundwater recharge and flood reduction in Dhaka

Dhaka faces two important challenges that could be addressed with the use of MAR systems: groundwater depletion and frequent urban floods during the monsoon. Infiltration of water from the roofs and/or paved surfaces into the ground could remove excess water during peak rain events, and at the same time recharge the groundwater, thus addressing both challenges at once. This can be accomplished by the use of a MAR system, where the vertical wells infiltrate the water from ground surface towards the groundwater. At the campus of the Dhaka University a pilot has started to test this option for managed aquifer recharge in the urbanized environment in Dhaka. This test is a follow up of already existing pilots implemented in the past years by WaterAiD, IWM and Dhaka WASA<sup>10</sup>.

### MAR system for arsenic reduction in Narail

In many areas of Bangladesh groundwater in shallow and some deep aquifers is contaminated with arsenic, posing a long-term health risk when it is used as drinking water. MAR systems could provide an option to reduce concentrations of arsenic in groundwater. Under this approach, rainwater, filtered pond water or river water is infiltrated directly into the arsenic contaminated aquifer. The periodical injection of (oxygen rich) water, which mixes with the groundwater, is expected to cause the arsenic to precipitate in the aquifer, thus removing it from the water<sup>11</sup>. This method is known as in-situ oxidation and is



already successfully applied for removal of iron (Netherlands) and manganese (Egypt). A first pilot to test this idea has started in Boronail Union, in Narail, where it is estimated that the 1,500 families are affected by arsenic contamination of the shallow groundwater and where the deep groundwater is not suitable for drinking.

#### **MAR system for domestic and agricultural use in the Blue Gold Polders**

The Blue Gold Program (BGP), a parallel project in Bangladesh, focuses on the empowerment of rural community organizations to sustainably manage flood control, drainage and irrigation infrastructure. Four polders of BGP lay within the area of the MAR-UNICEF project. There, water systems that are introduced by BGP are handed over to the Water Management Groups and Water Management Association. Additionally, the application of MAR systems is currently being explored for irrigation of vegetables and other high value crops. A feasibility study will be carried out in 2014 and it is expected that a pilot project will be implemented by BGP, Dhaka University and Acacia Water in 2015 with funding from a special innovation fund under the BGP program.

## **4.3 | Cross country learning**

A corresponding technique is used to provide water for irrigation in the Netherlands. Here, the availability of freshwater is threatened by salinization increases the risk for agricultural losses. As fresh water is one of the most important conditions for good agriculture in the area, securing fresh water buffers is of the utmost importance. By performing two projects with corresponding techniques in Bangladesh and the Netherlands, a lot of knowledge and experience has been shared regarding technology, project organisation and business models. The application of MAR systems developed in Bangladesh is much cheaper than the currently available technology in the Netherlands. Therefore, the lessons learned in Bangladesh provided the opportunity to extend the potential use of MAR systems from high-value crops to all kinds of agriculture in the

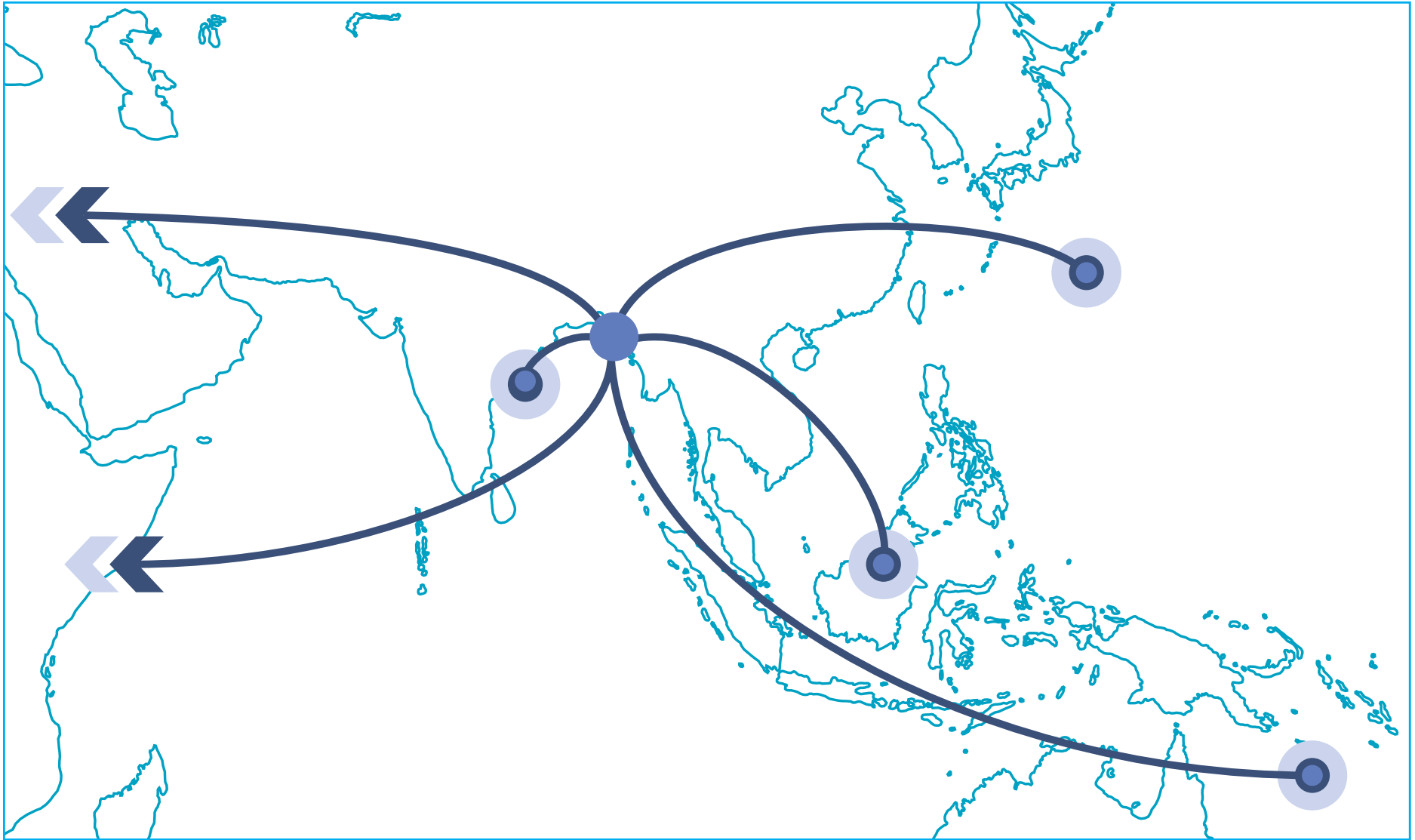
Netherlands. The other way around, technological developments in the Netherlands provide new insights to further optimize the MAR design. The cross-country learning between Bangladesh and the Netherlands has also generated new ideas to apply this technology to other water management challenges, such as; restoring groundwater levels in over pumped areas, reducing drought risk, and improving water quality through in situ removal of iron and arsenic.



Photo 11. Agriculture in the delta of Bangladesh.



Photo 12. Agriculture in the delta of the Netherlands.



# 5 Ambition

## Resilient coastal deltas through large scale application

The MAR-UNICEF project in Bangladesh demonstrated MAR systems as an attractive option for sustainable, disaster resilient water supply option for saline deltas. With Managed Aquifer Recharge, a substantial amount of fresh water can be stored underground and used as needed for drinking, domestic needs and agriculture. The  $\pm 100$  systems that were implemented during the pilot and subsequent upscaling phase showed the high potential of the technology. With further scaling up, it is anticipated that over a million people in coastal Bangladesh could be provided with sustainable, year-round access to safe drinking water with MAR systems.

MAR systems are a feasible option both in the short and long term. Geographical scaling of the MAR technology on a short term is manageable through replication of the systems that were piloted and upscaled under the current project. Further optimization of the systems could increase infiltration (and storage) capacity, optimize water quality and establish user conditions which will support large scale implementation. Construction of multiple systems in a concentrated area will result in a cost-effective replication.

In the long run, the development of a larger underground freshwater bubble, by increasing the amount of infiltration, can provide safe water for larger populations. Larger MAR systems could be combined with piped water schemes to provide safe drinking water to the household level. Both the ease of use and the cost-effectiveness of MAR systems could potentially can increase through this application at a larger scale.

Translating the present findings to future prospects shows that underground fresh water storage is a promising solution to tackle water scarcity

challenges. Population growth and potential impacts of climate change are expected to further stress the limited fresh water resources in the future. MAR systems can provide year round safe water in disaster prone areas, thereby increasing the resilience for disasters, climate change and scarcity, both in Bangladesh and other saline coastal deltas all over the world.



Photo 13. Field visit at a MAR pilot scheme.



# 6 Reports and references

This document is largely based on the progress reports and technical reports. These reports are prepared under the MAR-UNICEF project since 2009. For further detail on specific topics of interest we refer to the technical reports (TR) listed below. The reports are available on [www.acaciawater.com](http://www.acaciawater.com) from December 2014.

- TR 1 | Spatial Data Base for MAR application in Khulna District
- TR 2 | Financial and economic evaluation of MAR systems
- TR 3 | Social assessment for ownership and use of MAR systems (consultancy report by Dristhi)
- TR 4 | Testing and evaluation of MAR system performance
- TR 5 | Water Safety Plan for MAR systems (1st edition)
- TR 6 | Manual for MAR system implementation in saline areas.
- TR 7 | MAR system upscaling approach
- TR 8 | MAR system action research: lessons learned

<sup>1</sup>UNICEF Bangladesh, 2011. Bangladesh national drinking water quality survey 2009.

<sup>2</sup>3R consortium and Waterbuffer, 2014. Managing 'Sweet and Salt', waterbuffering in Coastal Zones.

<sup>3</sup>Tuinhof, A., Van Steenberg, F., Vos, P. and Tolk, L.. 2012. Profit from Storage. The costs and benefits of water buffering.

<sup>4</sup>[www.waternet.nl](http://www.waternet.nl).

<sup>5</sup>Van Steenberg, F. and Tuinhof, A., 2010. Managing the Water Buffer for Development and Climate Change Adaptation

<sup>6</sup>Zuurbier, K.G., Bakker, M., Zaadnoordijk, W.J, Stuyfzand, P.J.

<sup>7</sup>2013. Identification of potential sites for aquifer storage and recovery (ASR) in coastal areas using ASR performance estimation methods.

<sup>8</sup>Δ-MAR, Urbanizing Deltas of the World - full application, 2013.

<sup>9</sup>WaterAid Bangladesh.

<sup>10</sup>Rainwater harvesting in Bangladesh: Potentials, Challenges and Stakeholders' Responses, Publisher:, Editors: Dr. Md Ashiq Ur Rahman, ASM Shafiqur Rahman.

<sup>11</sup>Neil, C.W., Yang, Y.J., Jun, Y.S. (2012). Arsenic mobilization and attenuation by mineral-water interactions: implications for managed aquifer recharge. Journal of Environ. Monitoring, 14: 1772-1788.

<sup>12</sup>[www.spaarwater.com](http://www.spaarwater.com)





