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CONTEXT SPECIFIC SAFE WATER SUPPLY TECHNOLOGIES FOR VULNERABLE CLIMATIC AND GEOMORPHOLOGIC AREAS OF BANGLADESH

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ABSTRACT

The detection of arsenic in shallow groundwater threatens groundwater based water supply in Bangladesh. Seawater encroachment in coastal aquifers is another major problem for the availability of fresh water. On the other hand, surface water source is not suitable in many parts of the country. In addition, vulnerable climatic conditions and anticipated impact of climate change are putting more stress on the sustainable development of safe water resources. Therefore, one technology is not suitable for all areas due to different hydro meteorological conditions. The aim of this paper is to determine sustainable context-specific water supply technologies considering the climatic hazard and other vulnerabilities in 5 different hard to reach (HtR) areas, which are (a) drought prone, (b) flood prone, (c) char (sand bar), (d) coastal and (e) haor (swamp) areas. It is found from the study that more activities and effort is needed to ensure the water supply facilities for all, mainly in the HtR areas. Still expansion and improvement of the water supply services is required to satisfy the basic needs in these areas. Proper maintenance and monitoring of existing appropriate technologies are also important for sustainable use. Guidelines and user manuals need to be prepared as a tool to standardized procedures for installation and easy maintenance of technologies.

Introduction

The development of groundwater resources for potable use has increased substantially over the last four decades. Bangladesh depends mainly on groundwater sources to meet its domestic demand for potable water. Rural domestic water supplies are obtained mainly from tubewells fitted with hand pumps and dug wells. By early 1990's, Bangladesh had achieved almost universal (i.e. about 97%) drinking water supply coverage until the success was overshadowed by the presence of excessive arsenic in the shallow groundwater and saline water in coastal aquifers. Although groundwater is generally of better quality than surface water, it has the drawback of being complicated and costly to treat once it becomes contaminated.

Further progress in ensuring better water supply in rural Bangladesh, particularly in hard to reach (HtR) areas (e.g. floodplains, chars i.e. sand bars, haors i.e. large swamps, hill tracts, coastal areas, etc.) still remain a big challenge (GoB 2011). Water and excreta related diseases such as diarrhoea, worm infestation and a range of respiratory diseases still remain a major health concern in the country. During and after natural disasters like flood, cyclone, storm surges, etc. the coastal population suffer from a massive deficiency of safe drinking water and this results in the outbreak of waterborne diseases. Considering indicators and their respective criteria and ranking, 1144 HtR unions (21%) were identified under 6 different physiographic categories that spreads over 257 upazilas and 50 districts in Bangladesh(GoB 2011).

The geophysical conditions very often affect the availability and quality of as well as the accessibility to safe drinking water and sanitation facilities for the community (Figure 1). Five of such vulnerable geophysical or physiographical areas were selected for this study. Nachole Upazila of Chapai Nawabganj district lies on the Barind Tract, and is representing as drought prone area, that has the surface elevation of about 35 m above the mean sea level. Dewanganj upazila of Jamalpur district and Shibalaya upazila of Manikganj district have been representing as vulnerable charland and flood prone areas respectively. Riverine charland in the north-central region consisting of isolated villages, surrounded by rivers, is inundated by water for about six months during monsoon. River erosion and floods affect the char area. Floodplain in the central part of Bangladesh is characterized by low lying lands susceptible to annual flooding, river erosion and water logging. Haors in the north-eastern region has low-lying elevation where flood water remains for about 6 months and villages become isolated in the rainy season. Dakshin (south) Sunamganjupazila of Sunamganj district has been surveyed for representing haors. Saline water encroachment is the main problem in the coastal plain. Mongla upazila of Bagerhat district along the southwest coast has been selected where high salinity and anticipated impact of sea-level rise are major threats. Villages are located in the active tidal zones and cyclones and tidal surges affect the locality.

Water supply technologies like shallow tubewell (STW), deep tubewell (DTW), pond sand filter (PSF), both the community and household based rainwater harvesting system (RWHS), deep set pump (DSHTW), dug well (DW), arsenic-iron removal plant (AIRP), double platform tubewell, desalinization plant, piped water supply, etc. have been installed in the study areas by NGO Forum for Public Health along with other Government and non-Government organizations. Generally, as the water from the DTW is bacteriologically safe, the acceptability of this technology is higher than the STW, which has a risk of bacterial contamination from the nearby pit latrines, but this risk is lower than PSF and RWHS. Previous studies show that water from the PSF and RWHS are also capable of supplying safe water if designed and maintained properly (Ahmed 1999; Ferdausi & Bolkland 2000; Islam et al. 2007; Harun & Kabir 2013). However, the usefulness and efficiency of these technologies depend on geophysical and hydrogeological conditions as well as availability and quality of water. This study has been undertaken to assess the efficiency of the existing water supply technologies and to identify the risk factors of different technologies at different area specific geophysical conditions in the selected HtR areas.

Physiographic Divisions of the Study Area

Bangladesh covers a major portion of the Bengal Delta formed by the Ganges-Brahmaputra-Meghna (GBM) river system. About 80% of the land area of the country is flat and low elevated, intersected by numerous rivers and their distributaries. Bangladesh can be divided into seven major physiographic divisions: a) Hilly Regions, b) Pleistocene Uplands, c) Tippera Surface, d) Tista Fan, e) Flood Plains, f) Delta Plain and g) Sylhet Depression and Inland Marshes (Alam et al. 1991; GWTF 2002). Each of these divisions can be subdivided under distinguished characteristics of their own (Figure 1).

Nizampur union of the Nachole upazila under Barind has been surveyed for this study. The Pleistocene uplifted Terraces cover an area of about 10% of Bangladesh. The Barind Tract is located in the west of the Brahmaputra river. It falls on the central part of north Bangladesh and covers districts under Rajshahi division. The Barind Tract is the product of vertical movements of Pleistocene sediment and reaches a maximum height of 20 m above recent floodplains. Availability of adequate thickness of aquifer, i.e. groundwater storage from where water can be abstracted, is limited in Barind area. Annual precipitation is also less in this area and drought is a common phenomena. The available surface water sources like rivers and ponds dries up during winter and summer months. Due to major irrigation abstraction from the exploitable upper aquifers, groundwater table is depleting significantly. As a result, access to safe water is becoming more difficult. Climate change impacts are also making the situation more challenging as the incidences of drought events are becoming more frequent.

Dewanganj upazila of Jamalpur district and Shibalaya upazila of Manikganj district lie on Brahmaputra-Jamuna floodplain and are categorized under charland and flood prone areas. Chukaibari union of Dewanganj upazila and Teota union of have been selected for this study to represent the charland and flood prone areas respectively. The floodplains of the Ganges, the

Atrai, the Brahmaputra-Jamuna, the Old Brahmaputra, and the Meghna rivers cover approximately 40% of Bangladesh's landform. The elevation of the major part of the floodplain ranges from 3 to 5 m above the mean sea-level. The floodplain covers the central, north and northeastern part of the country. The Brahmapura-Jamuna floodplain is located between the Barind and Madhupur Tracts. Elevation of this surface is 29 m in the north and about 6 m in the south. The Ganges floodplain extends from the western border of the country, south of the Barind Tract, as far east as where it merges with the Jamuna floodplain. Landform of the floodplain is characterized by natural levees distributed in a mottled pattern which forms shallow depressions and small ridges. The HtR char areas under the floodplains are home of the poorest and most vulnerable communities of the country where water and sanitation coverage is far below the standard. These areas are vulnerable to seasonal flood and are submerged under water during monsoon for about 5-6 months. They are also subjected to river bank erosions that makes maintenance of the safe water sources and sanitation facilities very challenging. In these areas the groundwater table is shallow and the soil is predominantly sandy. Contamination of groundwater from open defecation and pit latrines is also a problem.

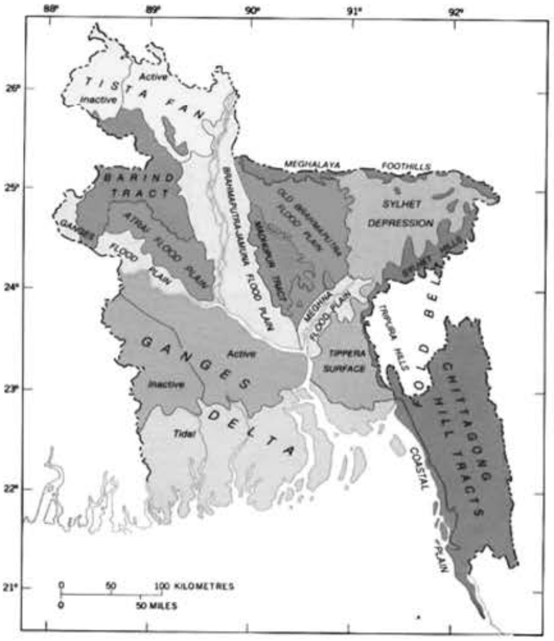


Fig. 1: Physiographic i.e. geophysical map of Bangladesh (Alam et. al., 1991) showing studied HtR upazilas.

Mongla upazila of Bagerhat district lies on tidal delta and falls under the coastal vicinity. Chila and Chandpai unions of Mongla upazila have been considered for this study to represent coastal vicinity. The delta complex covers about 32% of Bangladesh. The area south of a line drawn from the Ganges-Padma as far as the lower course of the Feni river in the southeast belongs to the delta of the GBM rivers. The Ganges is the greatest builder of the delta (70-80%). In the southwest, a part of the delta has been classified as the inactive delta, but the major part in the south and southeast is very active. The elevation of the delta is about 15 to 20 m from the mean sea level in the northwest and 1 to 2 m in the south. Many swamps (depressions) have developed in the substantial part of the delta. Holocene or Recent sediments from a few hundreds to thousands of meters cover the floodplains and the delta. The tidal delta covers the southern part of the Delta plain. This area is tide dominated and is considered as the active part of the delta. The landforms are characterized as tidal low land with weakly developed natural levees distributed in an irregular pattern. Numerous rivers, channels and tidal creekscriss-cross the area. Swamps and depressions are also present in the area. Estuarine deposits of silt, silty clay dominates in this area. The coastal belt is one of the major HtR areas, where people are frequently exposed to natural disasters like cyclone, storm surge, tidal flood and seawater encroachment. Anticipated impact of climate change, including rise of sea-level, would worsen the situation and the coastal area is most vulnerable to climate change impacts.

Shimulbak union of South Sunamganjupazila has been surveyed for this study. The Sylhet Depression is a tectonic basin subsiding at a very fast rate and is bounded by the hills of the frontier strip of Sylhet and Netrokona districts in the north and northeastern and Sylhet Hills in the east. Numerous lakes (beels) and large swamps (haors) cover the saucer shaped area of about 7,250 sq. km. The elevation of the central part of the depression is about 3 m above the sea level. The inland marshes are found scattered all over the country. The haor and wetlands remain inundated for about 6 to 8 months; therefore, crop cultivation is limited to a certain period of the time in the year. The water supply and sanitation situation in the area is appalling, with little coverage of hygienic latrines and widespread open defecation.

Previous Study and Investigation

National Strategy for Water and Sanitation: Hard to Reach Areas of Bangladesh 2011 (GoB 2011) has been enacted to improve safe drinking water and sanitation coverage in hydro-geologically and socio-economically difficult areas where people have services much less than the national standard. The specific objectives of this national strategy formulation are:

- to develop meaningful definitions of HtR areas and people, by considering adverse geographical locations, hydro-geological and socio-demographic conditions;
- to develop a criteria for isolating HtR areas based on assessment of present water and sanitation coverage, hydro-geologic conditions represented by water availability, vulnerability to natural disasters, and socio-economic parameters; and
- to identify challenges and thereby develop strategies for improved water supply and sanitation (WATSAN) services for the HtR areas.

Incorporation of climate change and disaster management strategies in development plan and encouragement of public-private partnership in WATSAN sector of HtR areas are also emphasized. For the purpose of drinking, cooking and personal hygiene, the basic minimum level of service is defined at 20 liters per capita per day and the source of safe drinking water should be within 50 meters of household premises.

Department of Public Health Engineering (DPHE) is the principal organization of the government, mainly for water supply and installation of sanitation facilities in rural areas of the country (GoB 1998). Considering the situation, DPHE under UNICEF supported Sanitation, Hygiene and Water Supply Project (GOB-UNICEF) proposed water technology options at union level. The major objective of the project was:

- identification of the union wise water supply technology, based on hydro-geological situation of the particular areas
- preparation of the GIS mapping for union-wise water options
- provide information to the water user group for preparation of union-wise water technology mapping

Declining water table, arsenic contamination in shallow groundwater, iron, manganese and salinity in groundwater, non availability of suitable aquifer, non-availability of protected and perennial surface water source round the year have been considered in selecting the different options. The project has given importance to arsenic mitigation approach as arsenic contamination has emerged as a great concern for groundwater based rural water supply system in Bangladesh. Different arsenic mitigation options have been discussed following "National Policy for Arsenic Mitigation 2004 and Implementation Plan for Arsenic Mitigation in Bangladesh" (GoB 2004). The major mitigations options proposed are, dug/ring well, pond sand filter, deep Tubewell, rain water harvesting as promotional option and arsenic removal technology.

Many government agencies, international organizations and NGO's have been working to investigate, survey and mitigate water issues and problems in order to ensure and provide facilities for all, including inhabitants of HtR areas. Many NGO's like NGO Forum for public Health, BRAC, WaterAid have also made remarkable contributions to this sector. NGO Forum conducted study, survey and investigations along with partner organizations to identify problem, assess demand and impact of existing facilities and select appropriate technologies suitable for different HtR areas.

NGO Forum has initiated a project titled 'Promotion of Water Supply, Sanitation and Hygiene in HtR Areas of Rural Bangladesh' with financial support from SDC in 2011 (NGOF-BCAS 2012). The project was targeted to accelerate the achievement of the Millennium Development Goals (MDGs) as well as the national target in the access to drinking water and adequate sanitation and hygiene practices. The aim of the project has been to promote decentralized and sustainable context-specific water supply and sanitation facilities by increasing the operation and maintenance capacity of the HtR community and creating their access to WATSAN services. To ensure access for the poor and vulnerable people during promotion of feasible technologies, emphasis has also been given to select proper sites by involving community people.

Study shows that most of the households belong to poor-category. Overall, 73.6% of households are below the upper poverty line (NGOF-BCAS 2012).

The most prevalent occupation, combining all eco-zones, is domestic work (41%) followed by day labor (16%) and agriculture (12%). In terms of awareness of safe water, the numbers of respondents were significant and it shows that 53.0% of respondents are aware of safe water. On an average 91.5% of total households in the study area have accessibility to improved water options. The study also reveals that the access of households to improved water options declines considerably in disaster period. During disaster period the use of pond water increases by 3.4% and river/canal water by 4.0%.

Needs assessment was evaluated qualitatively to identify the various risks and vulnerability of the HtR people in the selected ecosystems in relation to WATSAN; and this evaluation was quantified to identify the coping and adaptation needs of the local community in establishing and promoting climate resilient WATSAN technologies for the vulnerable communities. Community needs to improve the usage of safe water through the support for tubewell installation, arsenic testing, motivation and raising of awareness through the village level committees organized by the NGOs.

Methodology

In Bangladesh, participation of stakeholders and user beneficiaries during planning and implementation phase of water supply technologies installation is not a very common phenomenon, which is one of the causes behind the failure of many schemes (Chowdhury & Rahman 2008). Stakeholders need to be involved in the analysis to refining objectives and criteria (Bruen 2002). Therefore, along with the technical and design criteria used to assess the efficiency of technologies, user perceptions were considered for this study. Mixed method has been employed to conduct research and the sample unit was selected by random sampling method. A participatory multi-criteria analysis method was applied to evaluate the alternative water supply options in the area. The study also assessed technical and social feasibility of the different options. Applying multi-criteria analysis many studies have been conducted successfully in environmental and water resource management issues (Raju et al. 2000; Hostmann et al. 2005; and Herath 2004). The participatory techniques used in the study process includes:

- review of available documents and relevant national policies, plans and strategies
- a series of field visits to representative areas under all five physiographic zones along with the consideration of the following events,
  - ➢ focus group discussions to evaluate socio-economic conditions of the users, accessibility, affordability and acceptance of the water supply technologies by them, comments on advantages and limitations of the technologies and their suggestion
  - ➢ transect walks to record the topography, soils, natural vegetation, cultivation, human settle-ment patterns, local water supply technology and practices
  - ➢ observation of all types of installed water supply technologies by NGO Forum in collab-oration with partner NGOs.
- Review of the technology considering scientific and environmental aspects, hydrogeology, subsurface lithology, groundwater level and flow direction, water quality, acceptability, durability, seasonality as well as climate change and disaster management strategies
- preparation of maps, lithologic sections and interpretation of data as well as study and review findings
- Preparation of technical report with recommen-dations, wherever necessary.

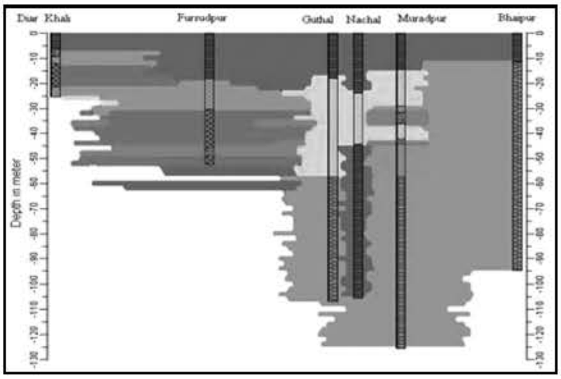
Results and Discussion

Upper aquifer system and groundwater trend in the study area

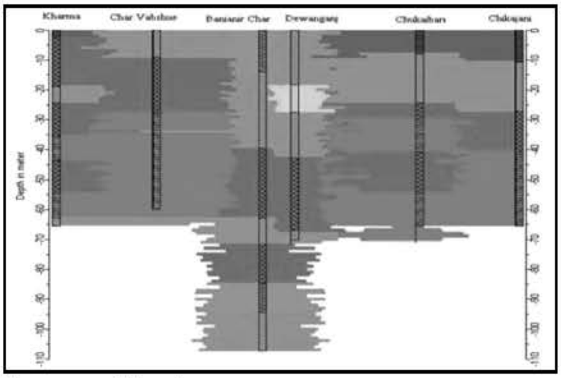
Hydrogeology, i.e. groundwater hydrology of Bengal Basin, is very complex and lithology, i.e. type, depth and thickness of aquifer sediments, may vary within very short distances as well as in different geomorphologic divisions. Aquifer, i.e. water saturated sediment formation in the sub-surface comprises fine to course sand, from which groundwater is abstracted for both water supply and irrigation (WARPO 2000). In Bengal Delta major aquifer systems belong to the Late Pleistocene to Holocene sediments. From the present available subsurface geological information it appears that most of the good aquifers of the country form at a depth between 30 and 120 m (GWTF 2002). But groundwater of most of shallow aquifers has been suffering from quality problems.

Lithologic cross-sections and dry season groundwater table contour maps of the studied upazilas are presented in Figure 2 and Figure 3 respectively. In the cross-section of lithologic logs of Nacholeupazila it is observed that the first aquifer extends from 10 to 55 m below surface dominated by brown very fine, fine and medium sand. A 10 to 20 m thick brown sticky and almost impermeable clay layer i.e. aquitard overlies this upper shallow aquifer that is a strong barrier to significant vertical recharge of rain or flood water to groundwater table. This layer also acts as a barrier for any sorts of surface contaminant. The upper aquifer is underlain by clay and silty clay layer till investigated depth of 120 m and is expected to extend few hundred meters deeper. Local drillers are unable to drill through this hard clay layer and therefore, the deep aquifers in the area are not well defined. In the western part of the upazila, the surface aquitard extends till the investigated depth of 95 m. The maximum and minimum groundwater table in Nacholeupazilla area, measured in BWDB observation wells are recorded between 10.0 and 30.0 m and 7 and 22.0 m respectively with the seasonal fluctuation of about 3-10 m. Therefore, water table in most of the areas declines below the suction limit of hand tubewells (7.5 m) almost all over the year which is mainly due to huge irrigation abstraction of groundwater from upper aquifers. Permanent declination is also noticed in many areas under Barind. In the High Barind area, significant land gradients exist that influence groundwater movement.

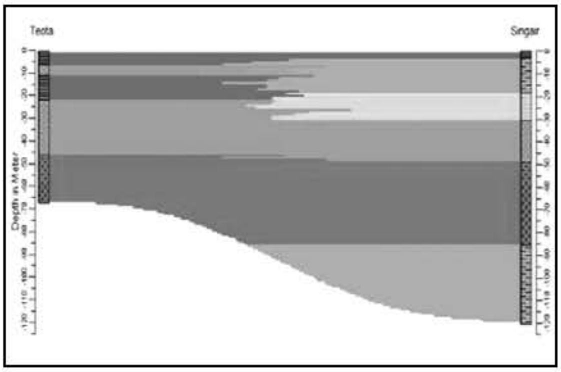
Under, the upper shallow or the first aquifer is encountered from surface at the depth of about 85 m and is dominated by fine sand followed by medium sand at the deeper part. The first aquifer is open to the surface, i.e. no surface aquitard is encountered in many areas, mainly in the vicinity of chars, and vulnerable to surface contamination. At some places, 3 to 12 m thick aquitard, i.e. clay layers, are encountered above the upper aquifer. In one borehole, lower aquitard is encountered at a depth of 85 m below surface that underlies the upper aquifer. The maximum and minimum groundwater tables under Dewanganjupazilla were measured between 6.5 and 9.0 m and 0 and 0.5 m respectively with the maximum fluctuation of about 6.0 m. The water table in the area generally remains within suction limit of hand tubewells, i.e. 7.5 m both in monsoon and dry irrigation period, except at a few locations. Lowered water table in dry season regains static level during monsoon.



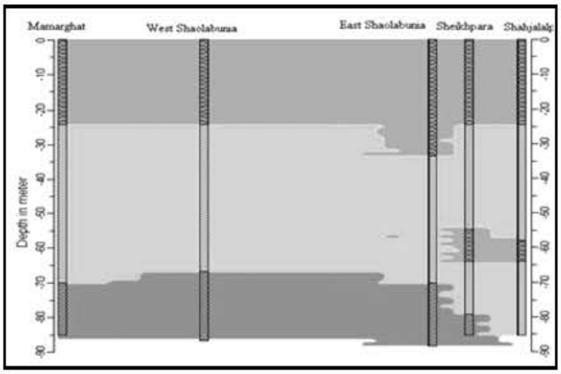
Nachole Upazila



Dewanganj Upazila



Shibalaya Upazila



Mongla Upazila

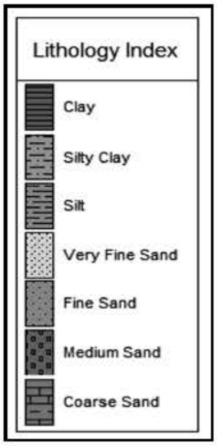
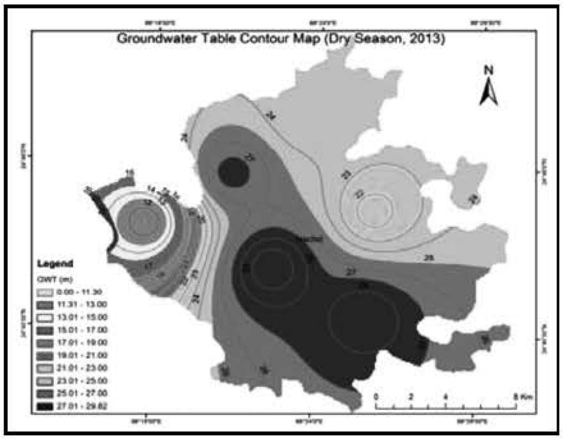
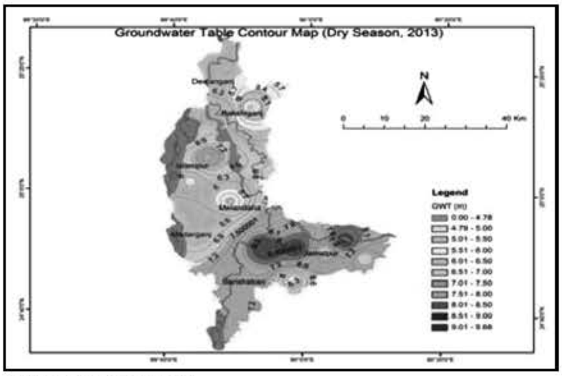


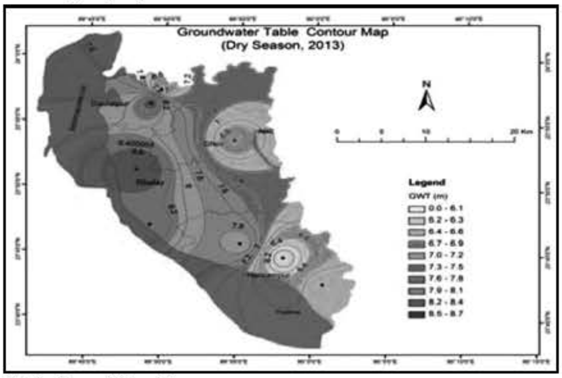
Fig 2: Extension of the upper shallow aquifers in the study area

It is observed that under area the upper or the first aquifer is encountered between 20 and 85 m depths overlain and underlain by clay and silty clay aquitards. The thickness of the surface aquitard varies between 5 and 20 m. The aquifer sediment consists of fine and medium sand. The lower aquitard extends from 85 m till the investigated depth of 120 m in the western part. The upper 5 m thick aquitard may not be thick enough to prevent surface contaminants, i.e. pit of latrine, to reach the groundwater table in the upper aquifer. Which also indicate that in many parts of the floodplain the aquifer type is unconfined. The maximum and minimum ranges of the groundwater table in Shibalayaupazilla area are recorded between 7.0 and 8.5 m and 0.5 and 1.0 m respectively with the seasonal fluctuation of about 6.5 to 7.0 m. The water table in the area remains within suction limit of hand tubewells, i.e. 7.5 m, both in monsoon and dry irrigation period, except at a few locations. Lowered water table in dry season generally regains to static level during monsoon.

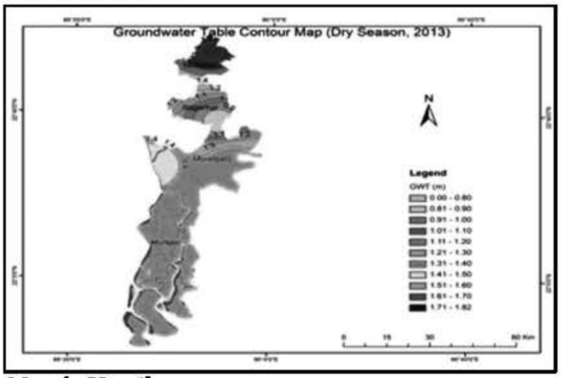




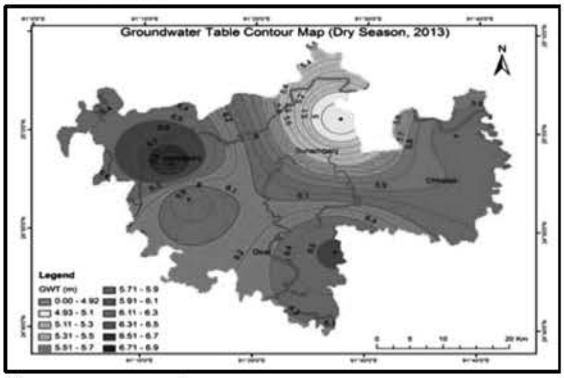
Dewanganj Upazila



Shibalaya Upazila



Mongla Upazila



Sunamganj Upazila

Fig 3: Maximum depths to the groundwater table (m) in dry season under study areas.

The upper or the first aquifer under Monglaupazila area is encountered from 25 m till the investigated depth of 90 m and consists of very fine and fine sand. The first aquifer is overlain by a 25 to 35 m thick silty clay aquitard. The maximum and minimum ranges of the groundwater tables in Monglaupazilla area are between 0.5 and 1.5 m and about 0 to 0.5 m respectively with maximum fluctuation of about 0 to 0.5 m. Almost no irrigation abstraction is noticed in the area due to high salinity in shallow groundwater. The seasonal water table fluctuation is higher in the vicinity of intensive groundwater irrigation zone, northern part of the coastal belt, which is less in the south.

Clay and silty clay dominates the haor area till the investigated depth of 200 m. It is observed that under Sunamganj area the upper or the first aquifer is encountered between 40 and 150 m, which consists of fine sand and is inter-bedded by thick clay aquitards. At many locations the upper aquifer is not encountered till this depth. The thickness of the surface aquitrad varies between 40 and 150 m. Therefore, though the available upper aquifers of the area are safe from any surface contamination, high arsenic is measured in shallow groundwater. The deeper aquifer is encountered below 180 m from the surface and main source of drinking water supply. The maximum and minimum ranges of the groundwater tables under Sunamganjupazilla area are recorded between 4.0 and 6.5 m and 3.0 and 3.5 m respectively with maximum fluctuation of about 1.0 m. Therefore, water table in the area remains within suction limit of hand tubewells, i.e. 7.5 m, both in monsoon and dry irrigation period. Due to low irrigation abstraction of groundwater in the area, the seasonal fluctuation of the water table is negligible. Lowered water table in dry season generally regains static level during monsoon. Most of the haor areas remain under water during monsoon and also before and after monsoon.

Installed water supply technologies

Shallow tubewell

Shallow hand tubewell (STW) is the most widely used low cost tube-well technology in Bangladesh that operates in suction mode. STW generally consists of no. 6 pump head with 38.0 mm (1.5 inch) diameter well pipes and filters. The foot valve and piston assembly are located into the pump head, which is mounted on top of the ground level (Figure 4). This suction mode hand tubewell lift water by creating vacuum within the cylinder of the pump by raising the piston and allowing water to enter into the cylinder to fill-up the vacuum. This pump can lift water when groundwater table is within 7.5 m from the ground surface. Where aquifer formation consists of very fine sand, artificial sand packing, i.e. shrouding or gravel packing, is required around the screen of the tubewell to increases the yield of the tubewell and prevents entry of fine sand into the screen.

STW is easy to install using local hand percussion method even by local low-skilled drillers. Its biggest advantage is its relatively low installation cost and no maintenance cost. This technology is applicable to shallow water tables but its major disadvantage is that it defunct quickly during dry irrigation season when the groundwater table declines below suction limit. STW is vulnerable to surface pollution due to poor disposal of human and industrial waste on the ground and to bacterial contamination sourced from nearby pit-latrine, depending on the distance and hydrogeologic conditions.

Amongst the studied unions, STWs are widely used only at Chukaibari char areas of Dewanganj upazila. At Teota of Shibalaya and Shimulbak of South Sunamganj, shallow groundwater is not suitable because of arsenic contamination and at Chadpai and Chila of Monglaupazila, salinity in the shallow aquifer is the major problem. At Nizampur of Nacholeupazila, due to declining groundwater table below the suction limit, no. 6 hand pumps are no more suitable option to withdraw groundwater and deep set hand pumps are in use here instead.

Deep tubewell

Deep hand tubewell (DTW) also operates in suction mode to withdraw groundwater from the deep aquifer where the potentiometric surface of groundwater table exists within 7.5 m below ground surface. The term of deep aquifer is used in a number of ways depending on the target of its use. Considering geology and hydro-stratigraphy, it may be defined as deeper aquifer (Holocene/Late Pleistocene) separated by impermeable or leaky clay/silty clay layer from the upper aquifers. The deep aquifer is separated from the overlying aquifers generally by one or more impermeable or leaky permeable clay layers of varied thickness. Where the deep aquifer is separated from the shallow aquifer by substantially thick (>10m) impervious layer, the aquifer water can sustainably be drawn for drinking purpose, though the groundwater in upper aquifers contain high arsenic or salinity. The depths of the deep aquifers are generally more than 250 in the basin part of Bangladesh. This water bearing zone comprises of medium to coarse sand in places that are inter-bedded with fine sand, silt and clay.

DTWs were selected in areas where deep aquifer is separated from arsenic contaminated and saline affected upper aquifers by substantially thick impervious layer. The annular space of the vertically straight bore holes of the DTWs was sealed at the level of impermeable strata to protect leakage of any contaminant from upper aquifers.

Generally, deep groundwater is of good quality and no arsenic or salinity is noticed in DTWs (>250-300 m depth) in Bangladesh. Hand pumps can be used in most parts of the study areas, except Barind, as groundwater table remains within suction limit of 7.5 m depth from the surface. However, DTW is costly for individual household. It can be provided for community water supply and the cost can be minimized by using multiple heads (Figure 4). Use of deep groundwater must be restricted only for drinking use as recharge rate in the deep aquifer is very low, i.e. precipitation water takes hundreds to a few thousand years to reach deep aquifers below 250-300 m depths (Zahid et al. 2014).

DTWs are installed at Shimulbak for fresh and safe source of water supply. Installation of DTW is difficult in areas of Teota and Nizampur due to presence of gravels and a thick layer of hard clay, respectively, between the shallow and the deeper aquifers. As STWs are withdrawing arsenic safe water in many places at Chukaibari, installation of DTW is not required at this stage except for arsenic contaminated areas.

Dual platform tubewell

Double platform tubewells (both STW and DTW) are useful in flood-prone areas to use as water options in the dry and flood seasons as well as to ensure supply during heavy flood (Figure 4). One platform is constructed about 1.0 to 1.5 m high, which keeps it free from flood threats and can be used during flood seasons. Another platform is at homestead land level, which is being used in the dry season. An elbow pipe is connected from the main boring pipe of the lower platform to the higher platform. This is thus, an innovative system for the char, floodplain and low elevated coastal areas and is highly context specific. During flood seasons, the head of the tubewell is replaced with the pipe of the higher platform to keep the tubewell free from flood water and surface pollutants.

Dual platform tubewells are installed in flood prone areas of Teota and Chukaibari unions of Shibalaya and Dewanganjupazillas, respectively. However, in water table declining areas, due to extensive irrigation in dry season, raised platform would increase the distance between groundwater table and hand pump beyond the suction limit.

Piped water supply

Piped water supply system has been constructed in rural Bangladesh using both STW and DTW (Figure 4) as well as treated pond water, for the clustered rural settlements. In respect of convenience in collection and use, only piped water can compete with existing system of tubewell water supply. Good numbers of stand-posts with water delivery taps are constructed for groups of households upto kilometer distances, i.e. water can be delivered to the close proximity of the users and the volume of supplied water can be controlled. Well maintained pipe water is protected from external contamination, but are vulnerable to damage of pipeline and surface pollution during natural disasters like storm surges and floods.

Piped water supply network has been constructed at Nizampur of Nachole Upazila using production tubewell and at Chadpai of Mongla using treated pond water.

Deep set hand tubewell

Lowering of water table and seasonal fluctuation of water table between wet and dry seasons are big issues for the tubewell based rural water supply. As number 6 suction mode pumps are not able to abstract groundwater when water table is below 7.5 m from the surface, development of new tubewell technology for low water table areas like Barind are required. Therefore, force mode pump has been introduced. When the depth of water table is marginal and declines during dry irrigation period, Tara tubewells may be given preference, as it can be used to abstract water from the water table that are 20-25 m below ground surface.

Deep set hand tubewell (DSHTW) operates in force mode and can abstract water from a depth of 30-37 m below ground level depending upon the type of DSHTW. For DSHTW, a 76 mm (3 inch) diameter housing/ casing, pipe length is extended upto a certain depth depending on the water table and piston assembly of the pump is set at that level by connecting a pump to the handle. The piston remains in submerged condition below water table.

DSHTWs are installed at Nizampur and required in most part of Barind where groundwater table declines below suction limit (7.5 m) of conventional hand tubewells in dry season, and has declined permanently in many areas. In other areas under the project, the groundwater table generally remains within the suction limit in both wet and dry seasons.

Arsenic iron removal plant

Arsenic-iron removal plants (AIRPs) are a relatively inexpensive way of removing/reducing arsenic content from groundwater for access to safe drinking water. Different options are provisionally certified by Bangladesh Council of Scientific and Industrial Research (BCSIR) of which most are household based and one is community based. These can be selected as an ultimate option, particularly, where tubewell and dug well is not feasible. Filter media needs to be replaces after the media being clogged.

Chemical processes that may influence AIRP performance are iron and arsenic oxidation, arsenic co-precipitation with iron, multiple iron additions, interference by organic and iron crystallization. Overall, AIRPs were shown to possess considerable promise for use in areas with high natural iron where users are concerned about arsenic and iron in their drinking water. However, the performance of AIRP is influenced by arsenic speciation, oxidant type, point of oxidant application, etc.

AIRPs have been constructed in arsenic affected areas of Teota and Chukaibari unions of Shibalaya and Dewanganjupazillas respectively.

Desalinization plant

The reverse osmosis (RO) process is based on the principal of osmosis and requires a membrane barrier to separate salts from water. Because RO technology requires considerably less energy to operate than distillation, it is considered to be the technology that would make desalination much more attainable for the world's saline prone water scarce areas. Desalination by RO requires the use of an osmotic membrane (allows water to pass through it at much higher rates than dissolved salts). The osmotic membrane is also referred to as a semi-permeable membrane because of its capability to allow some constituents to pass through it while holding back others. In the RO desalination process, a pressure greater than the osmotic pressure applied to the saline water will cause fresh water to flow through the membrane while holding back the salts. Saline water can be drawn from a surface water supply, a beach header-lateral face well system or a tubewell. Typically, groundwater is preferred because it provides a low turbidity feed water requiring less pretreatment. Shallow groundwater of the coastal belt with moderate salinity concentration (EC 5000-6000 µS/cm) are used as raw water for desalinization plants.

As tubewell water is used as raw-water, life time of the membrane is also higher. The initial installation cost of RO is high and needs proper maintenance. Moreover, careful disposal of the remaining, untreated, more salty water is required.

Desalinization plant using RO method is installed at Perikhali union of Rampalupazila and are feasible as wells useful for other saline prone coastal areas.

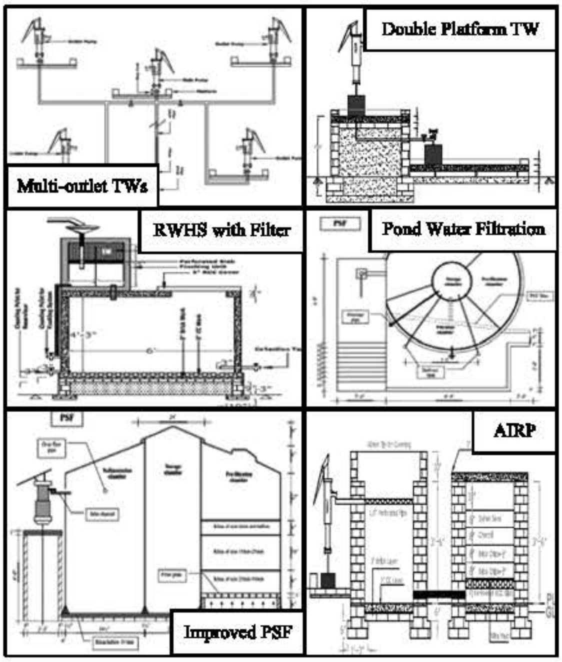


Fig 4: Improved design of NGO Forum installed different water supply technologies in the studied HtR areas.

Dug well

Dug well (DW) is the oldest method of groundwater withdrawal for water supplies. The water of the DW has been found to be free from dissolved arsenic and iron even in locations where STWs are contaminated. DWs are feasible in areas with stable soil layer at the top (a clay layer is preferable) and in the presence of sandy layer within 9 to 12 m.

For construction by manual digging, the wells should be at least 1.2 m in diameter. Large diameter wells may be constructed for community water supplies. The depth of the well is dependent on the depth of the water table and its seasonal fluctuations. The upper part of the well lining and the space between the wall and soil are properly sealed and the top of the well is covered by concrete slab to avoid contamination. A manually operated hand tubewell is installed to withdraw water from the DW.

DWs are easy to install and generally no cost is involved for maintenance. No special equipment or skill is required for the digging of DWs. Areas with loose sandy soil at the surface and more than 15 m consolidated clay, tidal zones of the costal belt, zones with peaty soil that causes an unpleasant taste and smell are not suitable for construction of DW. DWs are vulnerable to bacterial contamination, if not maintained properly. Percolation of contaminated surface water is the most common route of pollution of well water. However, concrete cover slab and installed hand pumps to withdraw water are good components to protect against pathogens.

DWs are constructed at Teota of Shibalayaupazila. Installation of DW is difficult in char areas due to instability of recently deposited sediments and not feasible in Barind area due to thick hard clay in the sub-surface and lowered groundwater table.

Pond sand filter

A prospective and low cost option for development of surface water based water supply system is the construction of community type Slow Sand Filters commonly known as PSF. The PSF is a low-cost technology with high efficiency in turbidity and bacterial removal. It has received preference as an alternative water supply system for medium sized settlements in arsenic affected areas. In this very simple process, raw water from pond is pumped up from a pond, the turbidity is reduced through the roughing filter and then the water is discharged into the filtration unit (Figure 4). The filtered water is then collected in a clear water reservoir by an under drainage system. The main precondition for this process is to preserve the pond water from any sorts of external pollution or contamination.

The horizontal roughing filter is divided into 3 parts: inlet tank, gravel zone and outlet tank. The gravel zone consists of 3 chambers loaded by different size of gravels (5-15 mm). The sand filter bed should be composed of 0.22 – 0.35 mm fine sand with a thickness of 60 to 120 cm. There is also a layer of coarse aggregate below the fine sand to support the sand against washing out through into under drainage system. The uniformity coefficient of sand should be from 2 to 3, which is indicated as well sorted sand grains. The size of the gravel zone is 5-15 mm. On average the operating period of a PSF between cleaning is usually two months, after which the sand in the bed needs to be cleaned and replaced. Iron content exceeding 5 mg/l will require treatment using iron removal unit. Dissolved iron in water is converted to an insoluble ferric form in contact with air. This form will be removed by settling it in the sedimentation tank and removing that remaining by filtration through a sand filter.

Operation and maintenance of PSF is easy and users are able to do it. PSF may not remove 100% of the pathogens from heavily contaminated surface water but has high bacteria removal efficiency. However, chlorination can remove 100% pathogens. It is difficult to find an appropriate/reserve pond for installation of PSF as people are using ponds for fish culture in Bangladesh adding chemical fertilizer.

PSFs are constructed at Chadpai and Chila, Teota and Chukaibari unions under Mongla, Shibalaya and Dewanganjupazilas and are feasible option for other fresh groundwater scarce areas too, if maintained properly.

Rain water harvesting system

As the annual rainfall in Bangladesh is about 2300 mm, rainwater harvesting system (RWHS) is feasible almost all over the country. The rain water is safe if it maintained hygienically. The main limitation of this option is non-availability of rain water round the year. However, it can be widely used as supplementary source. There should be a catchment area for rain water harvesting and the roofs of the houses are generally used as catchment area.

RWHS has 3 basic units, the catchment area (like corrugated roof top), supporting collection system (gutter and collection pipe) and storage tank made of ferro-cement, burned clay (motka), brick wall etc. (Figure 4). The collection pipe has an exit way beyond the connection with storage tank to let the first flush flow away. The down pipe has a net to bar mosquitoes, flies and dirt from entering into the storage tank. There is an end plug to stop flush discharge to enter water into the storage tank after flushing. In many RWHS an additional filtration unit is added on the top of the tank to ensure bacteria free water, sourced from catchment area.

Relatively cheap materials can be used for construction of RWHS containers. It has low maintenance cost and requirements. Collected rainwater can be consumed without treatment, if a clean collecting surface is used. RWHS provides a supply of safe water close to homes, schools or communities, encourages increased consumption and reduces the time women and children need for collecting water. Supplies can be contaminated by bird/animal droppings on catchment surfaces and guttering structures unless they are cleaned/flushed before use. However, added filtration system removes such bacterial contamination. Both for household and community levels, RWHSs are very useful as a source for seasonal or round the year fresh water supply and in the groundwater stressed or quality hazardous areas this is the best, low cost and feasible option.

RWHSs have been constructed at Teota, Chukaibari, Shimulbak and Chadpai and Chila unions of the studied areas under Shibalaya, Dewanganj, South Sunamganj and Mongla areas respectively. Low annual average precipitation in Barind area limits the use of rainwater.

Selection of area specific water supply technologies

Drought-prone Barind area

Nizampur union of Nacholeupazilla lies in ChapaiNawabganj district which is a part of the Barind Tract. The Barind is known for drought prone characteristics where average annual precipitation is less compared to the other parts of Bangladesh. The BMDA has been implementing large scale groundwater irrigation schemes in the area for the last few decades that lead to increased crop production. But, because of a huge irrigation abstraction of groundwater from upper aquifers, groundwater table has lowered below the suction limit (7.5 m) of hand tubewells in many areas of Barind, including Nizampur, causing scarcity of safe drinking water. People are unable to use tubewells with no. 6 hand pumps anymore and DSHTW has been introduced a few years ago to mitigate the problem by abstracting water from greater depths. The upper, almost impermeable clay layer below surface has a thickness of more than 8-5 m, which is not suitable for percolation of precipitation water and reduces recharge rates of groundwater. The thickness of hard clay below the upper aquifer is hundreds of meters and drilling with local methods is not possible. Therefore, the deep aquifer in the area is not well identified. Groundwater quality under Barind area is generally safe and where arsenic contamination is not noticed till exploitable depth of 50-60 m.

Considering water scarcity at Nizampur area and lowered groundwater table (upto 35 m below surface) below suction limit, NGO Forum, in cooperation with ASSEDO, installed DSHTWs and groundwater based piped water network for safe water supply. As no. 6 hand tubewell has no use in groundwater table declined localities of Barind, DSHTW is the most efficient water supply option in the area. However, piped water supply using large diameter production well may minimize the ultimate cost though the initial investment is high. More RWHS and PSF can also be constructed in the area to reduce pressure on groundwater resource. Arsenic content of groundwater in tested DSHTWs were found less than 0.003 mg/l, i.e. within the allowable limit set by World Health Organization (WHO 2008) and Department of Environment, Bangladesh (DoE 1997). Except DSHTW water of Tetulia village, iron concentrations of all wells were detected within allowable limit of 1.0 mg/l. The thick compact clay in the sub-surface protects groundwater from any surface contamination including pathogen bacteria sourced from pit-latrines.

At Jhenaipukur village, DSHTW has also been used to recharge preserve ponds during dry season for community use. Piped water supply using a production well of 35 m deep and 126 mm (5 inch) in diameter has been installed at Golabari village. Groundwater is withdrawn by submersible pump from the well to the overhead tank. About 225 families are receiving fresh and safe water from 38 stand-posts (water tapes). The maintenance of the technologies has been carried-out by Water Management Committees (WMCs) and the users. Users are very happy and satisfied with the quality and availability of water round the year in the highly water scarce zone. As per user's opinion, waterborne diseases have reduced and even been eliminated after the installation of the safe water supply facilities in the area. Though the initial investment for installation of the production well, storage and overhead tanks and pipeline network is expensive, considering the large number of beneficiaries and ensured safe water supply, this is a very efficient and feasible option.

To augment the storage of groundwater by artificial recharge technology, 5 numbers of 150 mm (6 inch) diameter recharge wells have been installed having the strainer location between 25 and 35 m depths. The thickness of the surface clay is 18 to 25 m in the vicinity. Roof of the village houses are used as catchment area for the precipitation to recharge groundwater. To ensure the quality of recharged rain water, filter materials (e.g. brick chip, coarse sand, etc.) are used in designing the wells. However, to assess the efficiency of this technology, recharge rates and volume, water quality after infiltration and comparison of groundwater table before and after installation of recharge wells needs to be studied. Based on the study findings and lithologic condition of the sub-surface, other technologies like recharge basin, sand pile, injection well, etc. may be considered for artificial recharge, wherever feasible.

Vulnerable Char areas

Regular seasonal flood and riverbank erosion are major problems for the Chukaibari union of, Jamalpur district lies on Brahmaputra river plain. Because of its braided river pattern, the Brahmaputra formed many large and small sand bars, locally named as chars. As chars are formed with recent deposition of river borne sediments dominated by fine and medium sand, the groundwater is generally safe from arsenic contamination. Therefore STW is the most popular source of fresh and safe water supply and the groundwater table generally remains within the suction limit of 7.5 m round the year. In the stable and older part of the union, shallow groundwater contains high arsenic above the limit of drinking water standard (10 µg/l of WHO and 50 µg/l of DoE, Bangladesh). In most areas, high iron is noticed but can be treated using sand filtration techniques. Due to regular seasonal flood most parts of the union are submerged under water during monsoon for 5-6 months and many existing tubewells become flooded with polluted surface water. River bank erosion causes shifting of population and loss of hand tubewells.

Considering the most visible problems, STWs (15-45 m deep), raised and dual platform tubewells, dug wells, iron removal plants (IRP) and AIRP have been installed in the area by NGO Forum in cooperation with Gonochetona. Arsenic content of groundwater and treated water in all tested STWs and AIRPs respectively are found within the allowable limit set by DoE, Bangladesh. Only in few samples arsenic content slightly exceeds above the WHO limit. Except a few water samples from STWs, iron concentration of all other wells and AIRPs were detected within allowable limit of 1.0 mg/l.

In char areas, STW is the most acceptable and low cost option as shallow groundwater is free from arsenic contamination. Areas with regular seasonal flood, dual platform tubewells should be constructed to get fresh water even during flood. However, the safe distance of STW from nearby pit latrine needs to be considered as the surface clay is not thick enough and leaky permeable. DW is not suitable because of very fine grained silty sand and instability of subsurface sediment during excavation. Where arsenic and iron is problem in more stable areas, people have accepted dug wells and AIRPs very gladly. All technologies including AIRPs are maintained and cleaned by user families under supervision of Village Development Committees (VDCs). 20-30 families are getting benefits from each AIRPs and DWs. However, water quality needs to be monitored regularly for dug wells and AIRPs. DTW can be installed where shallow groundwater is contaminated by arsenic. To minimize the cost of DTW installation, piped water network can be constructed in the stable parts for community water supply using DTWs.

Flood-prone areas

Seasonal flood and arsenic contamination in shallow groundwater are the major problems towards water supply services for the population of Teota union of, Manikganj district, which lies on Brahmaputra river plain. The Holocene sediments formed the floodplain aquifers and the shallow groundwater contains arsenic above the limit in drinking water in most of the area. Iron concentration is also high in upper aquifers. On the other hand, because of gravel enriched layers in the subsurface (about 70-100 m depth), installation of DTW is difficult by local manual methods. Groundwater table generally remains within the suction limit of 7.5 m in most of the areas round the year. Due to seasonal flood most parts of the union are submerged under water during monsoon for 3-4 months and many existing tubewells become flooded with polluted surface water and become defunct. Considering these challenges, brick made RWHS, raised and dual platform tubewells, dug wells, AIRP have been installed in the area by NGO Forum in cooperation with SEDA. Arsenic content of the treated water in all tested AIRPs were found within the allowable limit set by DoE, Bangladesh. Only in few samples, arsenic content slightly exceeds the WHO limit. Except a few water samples of STWs, iron concentration of all other wells and AIRPs were detected within the allowable limit of 1.0 mg/l. No Fecal Coliform (FC) was found in the tested water samples of RWHSs and DWs. RWHSs and AIRPs are maintained and cleaned by user families under supervision of Village Development Committees (VDCs).

In arsenic affected flood prone areas, DW, PSF, RWHS and groundwater based AIRPs are effective options at different circumstances for safe water supply. 15-30 families are getting benefits from each dug wells and AIRPs. RWHSs are useful for a family or few families with limited use of preserved water in dry season. Safe distance of STWs for AIRPs from nearby pit latrines needs to be considered to avoid bacterial contamination from the pit as the thickness of the surface clay in the areas is not significant and leaky. The groundwater table during monsoon is very close to the surface. Water quality needs to be monitored regularly for DWs, RWHSs and AIRPs. DTW (>300 m deep) can be installed for community water supply in the arsenic and iron affected areas. Dual platform DTWs are useful options for the flood-prone areas and are usable during flood by moving pumps on higher platforms. PSFs and DTWs can be installed for community water supply too.

Saline and disaster prone Coastal area

Natural calamities like cyclones, storm surges, tornadoes, seawater encroachment in the coastal eco-system and saline water intrusion in groundwater are the most common phenomena in the coastal areas of Bangladesh. In addition, coastal areas are also vulnerable to the anticipated impacts of climate changes like sea-level rises. Chila and Chandpai unions of Monglaupazila and Perikhali union of Rampalupazila of Bagerhat district lies on the coastal plain and have been suffering from disasters mentioned above. Amongst all, saline water in upper aquifers and arsenic contamination in shallow groundwater of a few areas limit the availability of safe water in the region. Water in tidal rivers in the vicinity is also saline and brackish, both in wet and dry seasons. Preserved ponds for fresh water supply suffer during storm surges when the area is inundated by saline and brackish water. However, harvested rain water and pond water is the main source of fresh water supply in the area. People collect rainwater during monsoon in motkas (earthen pots) and preserve it for a short period of time. Considering fresh water scarcity in the studied unions and salinity encroachment both in tidal rivers and upper aquifers, NGO Forum in cooperation with SEBA installed PSFs, both the RWHSs, with and without filter and the community based RWHSs, pond water based piped water supply and desalinization plant (by reverse osmosis) at Perikhali for safe water supply under the PWASH project. No Fecal Coliform (FC) was found in the tested water samples of RWHSs and DWs.

Piped water supply using privately owned treated pond water has been constructed at Chila. Pond water is withdrawn by submersible pump from the filtration system and send to the overhead tank. Solar power is used to operate the pump. About 250 families are receiving fresh and safe water from 20 stand-posts (water taps). PSFs are also very effective in the area and more than 200 people are getting benefits from a PSF having access to fresh water supply. Many families are using RWHSs and community based RWHSs almost round the year. The maintenance of the technologies has been carried out by Water Management Committees (WMCs) and the users. Users are very happy and satisfied with the quality and availability of water in the highly water scarce zone. However, regular monitoring of water quality for PSFs, RWHSs, and the piped water supply are required. At Perikhali, a desalinization plant with fresh water production capacity of 1000 liter/hour has been installed. Reverse osmosis method is used to treat saline groundwater as raw water with the EC value of about 6000 μS/cm. More than 200 families are currently collecting water from this point and can be expanded for more families. Use of electricity in future instead of petrol as power source would reduce the production cost of treated fresh water. Where preserved pond is available, PSF can be the most cost effective and suitable option for coastal water supply as groundwater in the upper aquifers is saline. RWHS can also be constructed, with limited use, during dry season. Desalinization plant can be constructed where preserved pond is not available. As the groundwater in upper aquifers contain high salinity, deep aquifer (>300 m) may contain fresh water. Therefore, DTWs may be installed for community water supply. Artificial recharge, i.e. managed aquifer recharge (MAR), may be augmented in coastal areas to improve shallow groundwater quality by reducing salinity concentration above arsenic contaminated layer and can be used for drinking purpose.

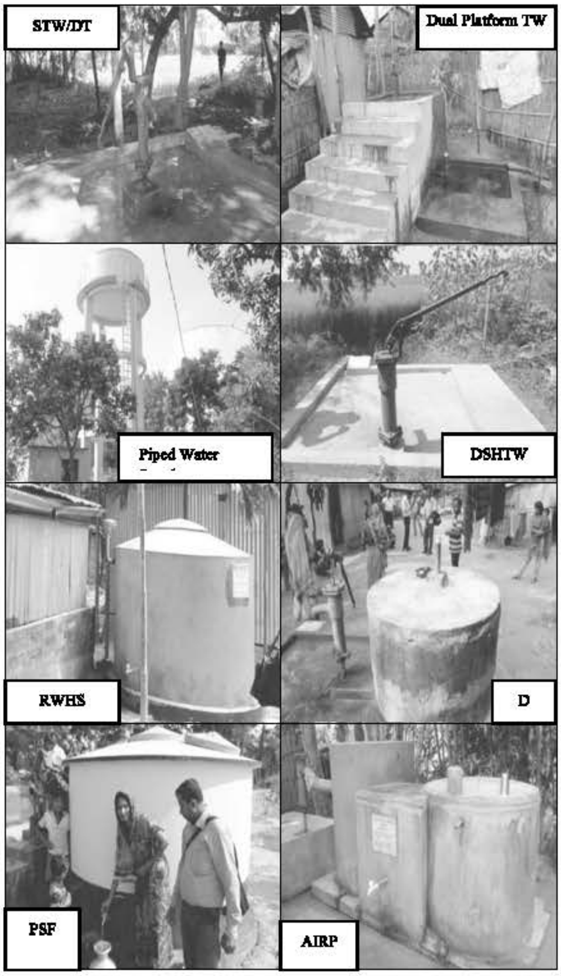


Fig 5: Examples of installed water technologies in different HtR areas by NGO Forum.

Water-logged Haor area

Haor areas are characterized by numerous lakes and large swamps and water logging for 6-8 months is a major challenge. Seasonal flood and arsenic contamination in shallow groundwater are the threats to water supply services for the population of Shimulbak union of South Sunamganjupazila, Sunamganj district. Clay and silty clay dominates the aquifer system in the area. The deep aquifer is encountered at about 180 m depth below ground surface and is the main source of fresh and safe drinking water supply in the area. Groundwater table generally remains within the suction limit of 7.5 m in most of the areas round the year.

Considering fresh water scarcity and non-availability of adequate dry lands in the studied union, NGO Forum in cooperation with ERA installed RWHSs, DTWs and multi outlet DTWs at Shimulbak for safe water supply. Arsenic content of groundwater in all tested DTWs were found within the allowable limit set by DoE, Bangladesh. Only in a few samples arsenic content slightly exceeds the WHO limit. Except few water samples of DTWs, iron concentration of all other wells were detected within allowable limit for drinking water supply.

At Shimulbak area, DTWs and RWHs are useful technologies for safe water supply. Regular monitoring of water quality for RWHSs and piped water supply is required. However, PSFs can be used too as fresh surface water is available round the year. At Khidirpur village, multi outlet DTW has been installed having the depth of about 230 m with about 1000 m pipeline network connecting multiple outlets of hand pumps. About 130 families are getting fresh water from this network and DTW is the first choice of the villagers for fresh water supply.

Because of arsenic contamination in shallow groundwater, DTW is the best option for water supply. Construction of multiple outlet head and piped water network can minimize the ultimate cost.

Summary

It is found from the study that more activities and effort are needed to ensure water and sanitation facilities for all, mainly in the hard to reach areas. Still expansion and improvement of the water supply services is required to satisfy the basic needs in these areas. The need is greater for under privileged groups and vulnerable regions. Proper maintenance and monitoring of existing technologies are also important for long-term sustainable use.

Guidelines and user manuals need to be prepared as a tool to keep standard procedures for installation and easy maintenance of different water supply technologies. Partner organizations should keep records of all installed technologies including design, local condition, geo-references, borehole lithologic logs of installed tubewells, major water quality parameters, e.g. pathogen, arsenic, iron, salinity etc. and any other important information required for improvement of and designing area specific technologies. Necessary measures need to be taken to prevent damage of technologies during natural disaster. Social mobilization needs to be developed through training of volunteers at village level for maintenance of technologies. Adequate awareness programs are needed to habituate uncommon types of technologies.

To augment the fresh water infiltration within the brackish and above the arsenic prone shallow groundwater simple recharge technology, like small diameter recharge basin/pile, can be constructed. Digging the subsurface clay (upto 3 to 5 m thick) and filling the hole by well sorted coarse sand, precipitation and uncontaminated pond water can be used to recharge groundwater in the vicinity of very shallow hand tubewell. This can be a low cost household level solution to provide safe water in hand tubewells by reducing the salt content in shallow groundwater in the coastal belt and fresh and safe recently recharged water in the arsenic prone areas above the arsenic contaminated zone.

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