Groundwater resources in the hard to reach areas of Bangladesh: Constraints for drinking water supply and strategies for sustainable use

M. Shahjahan Mondal
Institute of Water and Flood Management, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh
e-mail: mshahjahanmondal@iwfm.buet.ac.bd

Abstract: An assessment is made on the current groundwater use and further development potential in the hard to reach (HtR) areas of Bangladesh following a combination of secondary literature review and synthesis of primary information gathered from the fields. Also, primary analyses of groundwater quality, levels, recharge and use were done using secondary data. The findings reveal that the hydrogeology of the HtR areas is generally complex and highly variable except for the char areas of the Jamuna River. Groundwater mining is evident in both the high barind and hilly areas. There are also groundwater quality problems in both these areas. In contrast, recharge is not a constraint and there is no firm evidence of groundwater mining in the HtR areas of coasts, haors and chars. However, groundwater quality, particularly arsenic and salinity, appears to be a major concern. In addition, lateral intrusion of saline surface water due to sea level rise, and vertical infiltration from storm surge flooding pose a great risk to existing freshwater sources in the coasts and offshore islands. A number of drinking water supply options are currently in practice. The use and sustenance of the options are context specific and linked to technical, economic and social aspects. Multiple options are expected to continue at least in the near future in most of the HtR areas. However, tapping targeted aquifer, piped water supply and desalination plant are among the emerging options. Institutional coherence is needed for monitoring groundwater quality and regulating its use.

Keywords: Groundwater use, mining, groundwater quality, arsenic, drinking water supply, hard to reach areas

1. INTRODUCTION

Bangladesh opted for groundwater development since early 1960s because of favorable subsurface hydrogeology in most of the country. The country has witnessed a phenomenal increase in its irrigated area. Total irrigated area was about 1.2 million hectares (Mha) in the year of 1972-73, which increased to about 6.6 Mha in 2010-11. This increase has mainly been due to minor irrigation development using groundwater. The contribution of groundwater in irrigation has increased steadily over the years from about 40% during early 1980s to about 80% in recent years (Rahman and Mondal 2015). Apart from irrigation, drinking water supply in Bangladesh has almost entirely been based on groundwater source through the use of an estimated 8.6 million hand tube wells (HTWs). The country in the past had achieved a remarkable success of providing 97% of its population with access to improved water supply.

Such achievement, however, had been overshadowed by the discovery of arsenic in shallow groundwater in 1993. Since then, a number of hypotheses have been proposed to explain the occurrence and mobilization of arsenic in groundwater (Hoque 2010; Shamsudduha 2011). Due to arsenic alone, the population with access to safe water supply had come down to 74% from 97% (Ahmed et al. 2002). About 27% of the tube wells installed in shallow aquifer were found to be arsenic contaminated above the Bangladesh standard for arsenic in drinking water (50 µg/L) in a national hydro-chemical quality survey (BGS et al. 2001). The figure was 29% for the 270 arsenic affected upazilas (the middle tier of the local administrative units) in which about 5 million tube wells were tested under the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP 2004). A recent study (DPHE and JICA 2010) in 301 upazilas covering 55 districts (the highest tier of local administration) shows that out of 3132 unions (the lowest tier of local administration), only 137 have water supply devices free from arsenic contamination. Apart from arsenic, groundwater...
salinity is a major problem in ensuring safe drinking water in coastal areas. Around 12 million people in 9 coastal districts are severely in shortage of freshwater, where almost all freshwater sources, including both surface and groundwater, are contaminated with a salinity level beyond an acceptable limit (Islam and Mohammad 2013). There is also an iron problem in deep tube well (DTW) water almost all over Bangladesh (Hossain and Huda 1997). In addition, a high concentration of manganese is found in most areas of the country (Hasan and Ali 2010). About 46% of the shallow wells surveyed by BGS et al. (2001) contained manganese in excess of the World Health Organization (WHO) guideline value of 0.4 mg/L and 3.4% of deep wells exceeded such value.

Beside quality constraint, groundwater mining is occurring in many areas of the country due to over extraction. Excessive drawdown in many places renders suction mode tube wells inoperative during the critical period of the dry season. The combined quality-quantity status of groundwater may not be felicitous for drinking water supplies in future. In fact, a recent survey by the Bangladesh Bureau of Statistics (BBS 2015) reveals that only about half of the population has access to safe drinking water sources. The scenario is most likely to be worse than this for the rural people living in the Hard to Reach (HtR) areas of Bangladesh. The HtR areas are remote geographical locations with poor water and sanitation coverage, poor communication network and frequent occurrence of natural calamities (GoB 2011). The areas are identified and ranked based on six measurable indicators – four related to hydro-geophysical and two to socio-economic. A total of 1114 unions have been identified as the HtR areas, which spread over 257 upazilas of 50 districts. About 28 million people live in these HtR areas (Ahmed and Hassan 2012).

The present study was undertaken to review the current status of groundwater resources in the HtR areas in Bangladesh. The specific objectives of the study were (i) to assess the current status of groundwater hydrogeology, groundwater storage and quality in the HtR areas; (ii) to develop possible groundwater status scenarios for such areas; and (iii) to make recommendations for sustainable use of groundwater and to suggest appropriate technical solutions for safe drinking water.

The paper is organized such that in the next section, the methodology of the study and the data collected and reviewed to implement it are described. The groundwater hydrogeology, use and recharge for major physiographic units are then discussed. Following that, the groundwater scenarios that may appear in future for different units are developed. Afterwards, options for safe drinking water supply are suggested based on current practices, emerging trends and groundwater hydrogeology. Some conclusions are drawn and a few policy recommendations are made in the final section of the paper.

2. METHODOLOGY AND DATA

The approach followed in this study was a combination of desk review of secondary literatures and synthesis of field information gathered using participatory appraisal tools. Also, primary analyses of secondary data on groundwater levels, recharge and use were done. A systematic search in national and international databases was made to gather relevant literatures. The groundwater quality data of the national hydro-chemical quality survey conducted by the British Geological Survey (BGS) and the Department of Public Health Engineering (DPHE) (BGS and DPHE 2001) for different HtR upazilas were analyzed for arsenic, salinity, iron and manganese. Summary information on union-wise arsenic contamination of 14767 shallow tube wells (STWs) in the Khulna region assessed during September-December 2014 was available from the HYSAWA-SDC project. Groundwater quality data, in particular salinity, was also available from the DPHE, Bangladesh Water Development Board (BWDB) and Bangladesh Agricultural Development Corporation (BADC), which were also reviewed. Besides these, secondary information on testing of arsenic and piloting of safe water options in Jhikargachha upazila (Jakaria et al. 2003), testing of water quality including arsenic and bacteriological quality from different water supply technologies in Charghat upazila of Rajshahi district (Alam and Rahman 2010), testing of groundwater quality
including iron, manganese and arsenic in Sadar and Shibganj upazilas of Nawabganj district (Adhikary et al. 2013), testing of groundwater quality including iron in Sylhet City Corporation (Munna et al. 2015), etc., was available. Upazila-wise groundwater irrigated area was obtained from Minor Irrigation Survey Report 2012-13 (BADC 2013). Data on potential groundwater recharge and storage were obtained from the Water Resources Planning Organization (WARPO). Weekly groundwater level was collected from the BWDB and a time series analysis was carried out for groundwater level lowering and mining. A number of field visits were made to Khulna, Satkhira, Bagerhat, Jessore, Pabna, Sirajganj, Bogra and Chittagong areas during the years of 2014 and 2015 to gather relevant data and information using a number of participatory tools including focus group discussions, key person interviews, etc. In addition, a half-day national workshop was held in Dhaka on July 14, 2015 to share and validate the findings of the study. The workshop was well attended by more than 40 practitioners, professionals, implementers, and academicians and researchers from different government and non-government organizations both within and outside Dhaka.

The study was conducted in four divisions (Khulna, Rajshahi, Chittagong and Sylhet), out of seven, in the country. The HtR areas in these four divisions are relatively more vulnerable to drinking water crisis than that of the rest. There are 10, 8, 11 and 4 districts in the Khulna, Rajshahi, Chittagong and Sylhet divisions, respectively. However, five districts of the Khulna division and two districts of the Chittagong division do not have any HtR areas and were not included in this study. The HtR upazilas within these districts have different physiographic units such as coasts and offshore islands, hills, terraces, haors and chars, and hence groundwater characterization and development option are reported based on such units. This will provide better insights for future groundwater strategies. The locations of the different physiographic units within the study area are shown in Figure 1.

3. GROUNDWATER HYDROGEOLOGY, USE AND RECHARGE

3.1 Coasts and offshore islands

The subsurface hydrogeology of the coasts is very complex as the aquifer-aquitard alteration is frequent. The recent studies (IWM 2013; Taylor et al. 2014; Zahid 2008) suggest that, on a regional basis, the aquifers are hydraulically connected up to the investigated depth of 350-400 m. There are three aquifers – shallow, main and deep – overlain in many places by an upper clay and silt unit. The shallow, main and deep aquifers extend down to the depths of 50 m to over 100 m, 250-350 m and 300-350 m, respectively. The thickness of the top silty clay layer is also very high in this region. Most of the STWs pump water from the upper aquifer composed of fine and medium sands (Islam and Mohammad 2013). The coastal area is also low lying and criss-crossed by many tidal rivers. These rivers are hydraulically connected to the underlying alluvial aquifer system. Input to the aquifer system occurs mainly as natural recharge from rainfall.

Irrigation development in the coastal and offshore island areas has been low (Mondal 2015). Such development in Chittagong, Noakhali and Bagerhat districts has been below one-third of the net cultivable areas. The development by suction mode tube well technology has also been low in these districts.

The analysis of groundwater level data did not provide any indication of groundwater mining in the areas (Mondal 2015). Also, there was no indication of recharge constraint at present level of groundwater development as there was no decreasing trend in the annual highest groundwater level and the groundwater could recover to its historic highest level during the monsoon season. The usable recharge was estimated from the upazila-wise potential recharge data reported in Water Resources Planning Organization (WARPO 2000) and other relevant information. Such recharge was found to be no less than 1400 Mm$^3$ in the HtR upazilas of coasts and offshore islands where groundwater is now in use. Only a part of this usable recharge (about 30-35%) is now being
extracted for irrigation, domestic, commercial and industrial purposes. Thus, though the usable recharge was found to be relatively low (about 440 mm) and the groundwater storage within the top 22 m of the upper aquifer sequence was also low in the coasts and offshore islands due to the presence of upper clay in the aquifer system; they are not the potential constraints for groundwater development. It is rather the poor quality of groundwater which is the major constraint to groundwater development in the areas.

Groundwater in the coastal areas exhibit a number of quality problems including salinity, arsenic, iron and manganese. These quality problems vary spatially. Most of the areas are badly affected by groundwater salinity. Almost all the coastal upazilas contain arsenic in shallow groundwater beyond the Bangladesh drinking water quality standard. Groundwater in the coastal areas also contains excessive iron. Morrelganj, Paikgachha, Mongla, Dacope, Satkhira Sadar, Rampal, Mollahat, Debhata, Assasuni and Fakirhat upazilas are among the worst iron affected areas. Sarankhola, Noakhali Sadar, Kaliganj, Phultala, Fakirhat, Paikgachha, Morrelganj, Companiganj, Rampal and Shyammagar upazilas are badly affected by manganese in groundwater in excess of Bangladesh standard for manganese in drinking water (0.1 mg/L). In addition, about 35% of the households of the Khulna division have drinking water sources containing E. coli bacteria over 1 cfu/100 mL (BBS 2015).
3.2 Hilly areas

Limited information is available on the aquifer system in the hilly areas. The main aquifer in the north-eastern hilly region is of semi-confined to confined types and that in the south-eastern hilly region is of confined type. The hills in the north-east are overlain by Plio-Pleistocene and Holocene deposits (Mebius 2003). A prospective aquifer in the north-eastern hills is the highly weathered alluvial sands of the Dupi Tila formation (Hoque et al. 2003; Khan 2000; Mebius 2003). These sands are fine to medium grained and crop out in small hillocks in Sylhet and Moulvibazar districts and in some parts of Habiganj district. However, the permeability of these sands is lower than that of the alluvial deposits. The young gravelly sands also form a potential aquifer, although they are poorly sorted and contain large amounts of gravel and pebbles, making it difficult to use low-cost drilling techniques.

The thickness of the main aquifer in the Chittagong hilly areas is highly variable ranging from few tens of meters to more than 100 meters (MPO 1987). Surface clay of variable thickness covers the sandy materials which are exposed or found at shallow depths in the Chittagong hill ranges and occur at greater depths in the valley. In the hill ranges of Chittagong and the three Hill Tract districts, the water bearing formation consists of the Dupi Tila and Tipam sandstone formations and the sandstone interbeds of the Surma Group (Khan 2000). The northern/north-eastern hilly region has limited DTW and STW development potential and the area is considered unfavorable for extensive groundwater development. Flowing artesian wells used to occur on the periphery of the north-east and south-east regions in valleys (MPO 1987). The presence of such wells points to the existence of confined aquifers (Mebius 2003). In general, aquifer conditions in the hilly areas are poor in terms of the groundwater that can be extracted (WARPO 2000).

Irrigation development in hilly areas has been very low. For example, in Rangamati district, the total area is 61,160 ha, of which only about 25% is cultivable. About 6% of this cultivable land is presently under irrigation and that is by low lift pump using surface water. This indicates that the aquifer condition in the hilly areas is not favorable for groundwater-based irrigation development.

The groundwater level in the hilly areas also shows some evidence of groundwater mining (Mondal 2015). Both the annual lowest and highest levels show decreasing trends in majority of the places, in particular in the Chittagong hill tracts and Kanaighat upazila of Sylhet district. Thus, further increase in groundwater use in hilly areas is likely to be limited from a resource sustainability perspective, and regulation of groundwater use and protection of surface water sources are warranted.

The major quality concern with the use of groundwater in the hilly areas is the high concentration of iron and manganese. Almost all the upazilas have both iron and manganese problems. It also appeared that the iron and manganese problems are generic in nature in hilly aquifers irrespective of their locations in the south-east or north-east region of the country. Though groundwater quality data was not available for the three hill districts, it is inferred that these areas also have iron and manganese problems in groundwater. Apart from iron and manganese, about 48% and 62% of the households of the Chittagong and Sylhet divisions, respectively, fetch drinking water from sources containing E. coli bacteria over 1 cfu/100 mL (BBS 2015). However, there is no arsenic contamination above WHO guideline value in the three hill districts for which arsenic analysis has been carried out from 489 HTW and 82 DTW water samples (Chakraborti et al. 1999).

3.3 Barind areas

The aquifer system in the barind areas is predominantly semi-confined. However, unconfined, confined and multiple aquifers are also found both locally and regionally. Hydro-stratigraphic units of the area have recently been defined as Clay Top, Upper Aquifer, Clay Middle, Lower Aquifer and Clay Bottom (IWM 2011). The Clay Middle is not a continuous layer, and the upper and lower aquifers are interconnected. Thus, one aquifer unit usually exists within the exploited depth. The thickness of the upper part of the aquifer ranges from 10 m to 35 m and that of the lower part from
20 m to 70 m. The lower part of the aquifer is composed of medium to coarse-grained sand with occasional fine sediment lenses, and is the principal source of groundwater production (IWM 2011).

Groundwater development in the barind areas has been higher than that in the rest of the country. For example, the actual irrigated area in Naogaon district was higher than the net cultivable area in 2012-13 (BADC 2013). Thus, some of the areas have more than one irrigated crops during the rabi season. The use of groundwater technologies has also been a well mix of STWs and DTWs.

There is some concrete evidence that groundwater mining is occurring in the barind areas. Both the annual maximum and minimum groundwater levels are declining at significant rates. The usable recharge is estimated to be about 2200 Mm$^3$ within its HtR upazilas. Current groundwater extraction for irrigation, domestic, commercial and industrial purposes is at or more than this volume. The Clay Top, which varies in thickness from 2 m to 20 m, is an important control for aquifer recharge from rainfall. Though it was thought earlier that the overlying barind clay does not prevent the potential recharge from moving through to the underlying aquifer (Zaman and Rushton 2003), the present evidence and the WARPO (2000) data do not support this. The usable recharge in this area is found to be the lowest in the country (about 375 mm). Also, WARPO identified potential recharge as a constraint to full irrigation development in Nachole, Charghat, Godagari, Paba, Tanore, Niamatpur, and Patnitala upazilas. Thus, it appears that the present level and trend of groundwater development in the barind areas are not sustainable in the long run. Shamsudduha et al. (2009) also reported a declining groundwater level in the north-western part of the country and termed the irrigation supplies from the shallow aquifers in the high barind tract as unsustainable.

Like the hilly areas, the barind areas have iron and manganese problems in groundwater. Most of the upazilas have some degree of iron problem and all the upazilas have manganese problem. However, the iron problem is less severe in the barind areas compared to that in the hilly areas. In addition to iron and manganese problems, three upazilas (Paba and Mohanpur of Rajshahi district, and Manda of Naogaon district) have arsenic problem. About 31% of the households of the Rajshahi division fetch drinking water from sources containing E. coli bacteria over 1 cfu/100 mL (BBS 2015). Among the barind areas, Bogra has the best groundwater in quality.

### 3.4 Haor areas

The haor areas are underlain by a thick sequence of Quaternary deposits (Mebius 2003). These Quaternary deposits and the Dupi Tila formation below constitute the potential aquifers. The areas have an aquifer system of semi-confined to confined types. Most of the areas are covered by alluvial clay and silt deposits of the Meghna River and its tributaries (Mebius 2003). The sediments are not as well sorted and uniform as the deposits of the Brahmaputra River to the west. The top silty clay layer of the system is relatively thick and the main aquifer is located at relatively greater depth below the land surface (MPO 1987). Generally the alluvial deposits in the haor areas show rapid lithological changes, both vertically and laterally. Probably all Quaternary aquifers in the haor areas are of a local character (Mebius 2003). In Sunamganj district, a shallow alluvial aquifer is also available which is used for domestic water supplies with HTWs screened at 10-60 m below the land surface (Joarder et al. 2008). Irrigation wells typically tap deeper aquifers in the region at 70-100 m depth. In some areas of the district, DTWs have been installed at a depth of 150 m or more to avoid high salinity at shallower levels (Joarder et al. 2008). The main aquifer of the haor areas has low transmissivity. The specific yield is also low in the central part of the haor basin.

Irrigation development in the haor areas has been moderate, except for Sylhet where such development has been very low (Mondal 2015). A major part of this irrigation development has also been by using surface water based low lift pumps. Thus, groundwater use in the haor areas has been in general very low. However, in Baniachong and Ajmiriganj areas, a good number of DTWs are used to irrigate rabi crops.

The groundwater recharge in the haor areas is high due to high rainfall, and extensive, deep and extended period of flooding. The usable recharge is estimated to be about 3925 Mm$^3$ (about 735 mm) within the HtR upazilas of the haors. Current groundwater use for irrigation, domestic,
commercial and industrial purposes is very low (about 10%) compared to the recharge. Even with a low level of groundwater development, there is some scattered evidence of groundwater mining in the haor areas. However, the evidence is not as strong as it is in the barind areas and could be due to the localized character of the aquifer.

The presence of iron in groundwater is an acute problem for the haor areas. Except the Dharmapasha upazila, all other upazilas in the haor region have iron problem. All upazilas except Jagannathpur of Sunamganj district also have arsenic in groundwater exceeding the Bangladesh standard. Even the deeper aquifer in Chhatak and Sadar upazilas, where data was available from DTWs, have arsenic problem. The worst-affected upazilas are Derai, Dharmapasha and Jamalganj, where more than 50% hand/shallow tube wells contain arsenic exceeding the Bangladesh standard.

All the upazilas of the haor region have a manganese problem in groundwater. The badly affected upazilas are Nabiganj, Baniachong, Bishwambarpur, Jagannathpur, Derai, Jamalganj and Companiganj. In addition to the above chemical quality concerns, there is also a major microbiological quality concern with the source water in the haor region as about 62% households of the Sylhet division fetch drinking water from sources containing E. coli bacteria over 1 cfu/100 mL (BBS 2015).

3.5 Char areas

The aquifer systems in the Jamuna chars are of unconfined to semi-confined types and that in the Meghna chars are of confined, multiple or semi-confined type. In the Meghna chars, an upper, fine-grained aquifer is separated from a lower, medium-sand aquifer by a thick aquitard of grey, fine sandy silt (Hoque et al. 2003). The top silty clay layer is thick, and the main aquifer is at great depth. In contrast, the silty clay layer is thin, and the main aquifer is at shallow depth in the Jamuna chars.

In the char areas of the Jamuna River, irrigation development has been high (Mondal 2015). In contrast, in the char areas of the Meghna River, irrigation development has been low. The use of surface water based low lift pumps has also been high in the Meghna chars. Thus, groundwater development in the Meghna char areas has been very low.

As groundwater development in the Meghna char areas has been low, there is no strong evidence of groundwater mining in the Meghna chars. In fact, usable recharge is found to be very high (about 1020 mm) in these areas. However, the usable recharge is comparatively low (about 660 mm) and groundwater use high (about 40%) in the Jamuna chars. As such there is some scattered evidence of groundwater level shifts and mining in the Jamuna chars which is in line with the overall regional pattern of groundwater mining in the barind areas.

The groundwater quality in the Meghna char areas is worse than that of the Jamuna char areas. The char areas in the south-east suffer from both arsenic and iron problems. Even the option for DTW in Chandpur district is constrained by the presence of salinity in the deep aquifer. Though the upper aquifer is basically fresh, the lower aquifer contains salinity throughout its thickness in this region (Hoque et al. 2003). In Hajiganj, even the deep aquifer contains arsenic. The Jamuna char areas have iron and arsenic problems. All the char upazilas contain manganese in excessive quantity in groundwater. The manganese severity is more in the north-west char areas than that of the south-east char areas.

4. FUTURE GROUNDWATER SCENARIO

Evidence of groundwater mining, presence of contaminants such as arsenic, salinity, iron and manganese, and unfavorable physical condition of an aquifer are the primary barriers for sustenance groundwater use. These factors vary with the geographical locations such as coast, hill, terrace, haor and char. Based on the current and emerging conditions of these factors, future groundwater scenario for a particular geographical area is depicted here.
Within a major part of coasts and offshore islands, fresh groundwater exists at a depth of about 300 m. The magnitude of this resource is unknown, but believed to be limited (WARPO 2000), non-permanent (World Bank 2010) and non-renewable (Deltares et al. 2015). Also, shallow lenses of fresh groundwater exist locally, the occurrence of which is largely controlled by local relief and aquifer conditions. The fresh groundwater lenses, also known as perched aquifers, are maintained by recharge from rainfall. Surface clays are relatively thick in the south-west coastal region. Thus, the physical characteristics of the aquifer pose a constraint to groundwater development in the coastal region. On top of this, groundwater salinity is a major constraint which may further aggravate under global warming induced sea level rise, reduced freshwater supplies from upstream and increased groundwater pumping. However, the risk of groundwater salinization from lateral intrusion of sea water is low. Vertical infiltration of saltwater from storm surge or tidal inundation or shrimp ponds, particularly in low-topography areas and where upper clay is absent, poses a great risk to salinization of fresh groundwater sources. Groundwater salinization may also occur from seepage and percolation of seawater that naturally moves further up a river due to reduced fresh water supplies from upstream or sea level rise during the dry season. Pumping is likely to induce mixing of existing saline groundwater with fresh groundwater and accelerate intrusion of saline surface water to fresh aquifer. Overall, the groundwater scenario for the coastal region is rated as moderately to highly constrained (Figure 2).

The subsurface stratigraphy of the hills proves to be formidable for groundwater extraction at individual household level due to uncertain, deeper and unfavorable aquifer condition and high initial cost of drilling and tube well installation. Since the aquifer is confined, multiple, or semi-confined in nature, its recharge and groundwater storage are also uncertain. Many cases of drying and disappearance of the springs fed from groundwater sources are already reported. Groundwater piezometric levels also show some scattered evidences of groundwater mining. There are also iron and manganese problems in groundwater. Overall, the groundwater scenario is judged to be moderately to highly constrained. The little or no groundwater development in the hilly areas also supports such future groundwater outlook for the regions.

In the high barind areas, the thickness of surface clays is often in excess of 30 m. This upper clay has a low vertical permeability (<3 mm/day) and it along with a low rainfall in the area reduces recharge to groundwater. As such potential recharge is a constraint to full development in many upazilas. Already, there are evidences of groundwater mining in the high barind areas. There are also some quality constraints. As on the level barind areas, aquifer physical characteristics and mining are not so strong; the overall groundwater scenario in the barind is rated as lowly to moderately constrained (Figure 2).

In the haor basin, the occurrence of very thick surface clays largely limits the development of groundwater. Groundwater is available in small quantities and is mainly reserved for potable water supply (WARPO 2000). Though the potential recharge is high (MPO 1987) due to high rainfall and deep, extensive and long-duration flooding, and does not appear to be a constraint for groundwater development in the basin, there is some evidence of groundwater mining in the basin. Also, there
are quality constraints (iron, manganese and arsenic) for groundwater use for drinking purpose. The overall groundwater scenario is rated as lowly to moderately constrained by aquifer physical characteristics and groundwater quality.

Apart from some arsenic, iron and manganese problems, there are no other major constraints for groundwater development in the char areas of the Jamuna River. In contrast, arsenic and iron are major constraints for groundwater development in the char areas of the Meghna River.

5. SAFE WATER OPTIONS

Given the aquifer physical constraints and widespread quality constraints, the coastal people have adopted a number of drinking water supply options (Table 1). These include HTW, DTW, open pond, rooftop rainwater harvesting (RWH), rainwater preserved in ponds and filtered adopting indigenous technology like pond sand filter (PSF), groundwater recharged with freshwater termed as managed aquifer recharge (MAR), desalination plant and piped water supply from freshwater pocket sources (Islam and Mohammad 2013; Mondal and Khan 2012). Groundwater based desalination plant as found in Gilabari, Koyra upazila and in Laudobe and Bajua. Dacope upazila of Khulna district and piped water supply based on fresh groundwater source as found in Pakhimara, Shyamnagar upazila of Satkhira district or surface water source as is currently being planned in Rayenda, Sarankhola upazila of Bagerhat district are among the emerging technologies in the coastal saline-prone areas. However, it would be pragmatic at least in medium term to support different options depending on specific local hydro-geologic condition, socio-economic situation and local people’s choice.

As there exist aquifer physical constraints in the hilly areas, a number of drinking water supply options are in use (Table 1). These include DTW, HTW, river/chhara/lake/spring water, pond water and rain water harvester (Alam et al. 2006; Chakraborti et al. 1999; Islam et al. 2003; IWFM 2012; Munna et al. 2015). The hilly areas are mostly free from arsenic contamination of groundwater, but have iron and manganese problems. It is underlain by a medium to coarse sand formation of Pliocene epoch known as Dupi Tila, which contains arsenic free water. As quantification of the availability of this water has not been made and there are contradictory statements about this resource – limited (WARPO 2000) versus considerable (Chakraborti et al. 1999), the use of different options should be encouraged. Surface water sources should be protected and water use for agricultural and industrial purposes should be regulated.

Barind area, in particular high barind area of Rajshahi, Nawabganj and Naogaon districts, is drought prone. Groundwater level is far below the land surface and it is going down over the years. Shallow aquifer is iron, manganese and arsenic contaminated in some places (Adhikary et al. 2013). These together have created an acute crisis of drinking water in the region. Apart from tube wells, surface water, rainwater and dug well water are used for drinking purpose. The Barind Multipurpose Development Authority (BMDA) is also supplying drinking water from its DTWs originally installed for irrigation purpose in some parts of the dried tract. Since 1995, it has constructed about 1100 water supply installations and 50 other necessary infrastructures and provided drinking water to about 1.2 million people. As groundwater mining is already evident, groundwater use regulation may be put in practice in this region for sustainable resource utilization.

A few drinking water supply technologies are in use in the haor areas (Table 1). As potential recharge is not a constraint for groundwater development in the region and groundwater use is low, further increase in groundwater use may not be a problem as far as quantity of water is concerned. Also, as the upper aquifer is arsenic contaminated in many places and the main aquifer is a Dupi Tila formation, deeper aquifer based drinking water supply can be a preferred option if the occurrence of natural gas is not a problem.

Apart from iron, manganese and, in some cases, arsenic, there is no other major constraint for groundwater development in the Jamuna char areas. Deep HTW can be a potential option for supplying drinking water in arsenic affected areas. The Meghna char areas are arsenic hotspots and have salinity and iron problems. As such a diversified set of technologies are in use for drinking
water supply (Table 1). Its water supply options could be more or less similar to that of the coastal region reported earlier in this section.

Table 1. Drinking water supply practices in different physiographic settings in Bangladesh

<table>
<thead>
<tr>
<th>Physiographic setting</th>
<th>Drinking water supply practices</th>
<th>Major groundwater quality concern</th>
<th>Source of information</th>
<th>Potential option for drinking water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coast</td>
<td>PSF, RWH, desalination plant, piped water supply, MAR, open pond, HTW, DTW, membrane filter and water vending</td>
<td>Salinity, As, Fe, Mn</td>
<td>Islam and Mohammad 2013; Mondal and Khan 2012</td>
<td>Deep HTW, piped water supply, desalination plant, adaptive technology</td>
</tr>
<tr>
<td>Hill</td>
<td>DTW, HTW, pond, river, chara, spring, RWH, gravity flow system (GFS), dug well and infiltration gallery (IFG)</td>
<td>Fe</td>
<td>Alam et al. 2006; Chakraborti et al. 1999; Islam et al. 2003; IWFM 2012; Mallick and Das 2003; Munna et al. 2015</td>
<td>Small-scale technologies, deep HTW, protection of surface water sources, regulation of GW use, control of land use</td>
</tr>
<tr>
<td>Barind</td>
<td>DTW, HTW, pond, river, canal, beel, dug well and RWH</td>
<td>Fe, Mn and As are higher (Sadar and Shibganj upazilas of Nawabganj district)</td>
<td>Alam and Rahman 2010; Adhikary et al. 2013</td>
<td>Groundwater regulation</td>
</tr>
<tr>
<td>Haor</td>
<td>HTW, dug well and DTW</td>
<td>Fe, As</td>
<td>Chowdhury et al. 2012; Joarder et al. 2008</td>
<td>Deep HTW/ DTW</td>
</tr>
<tr>
<td>Char (Jamuna)</td>
<td>HTW</td>
<td>Fe, As</td>
<td>Mondal and Khan 2012; IWFM and PPDM 2010</td>
<td>Deep HTW in arsenic prone area</td>
</tr>
<tr>
<td>Char (Meghna)</td>
<td>DTW, HTW, PSF, arsenic-iron removal plant (AIRP), piped water supply and RWH</td>
<td>As, Fe, Mn, salinity</td>
<td>NGO Forum 2015</td>
<td>Same as coast</td>
</tr>
</tbody>
</table>

5.1 Arsenic-safe water options

As the arsenic toxicity has no known effective treatment, two main approaches are suggested for mitigation of arsenic problem in drinking water: arsenic avoidance and arsenic removal (Ahmed 2003; Mallick and Das 2003). An alternative water supply option based on an arsenic-safe water source can be created for arsenic avoidance. There are three potential sources of arsenic-free drinking water, namely treated surface water (pond and river), rainwater and groundwater. Different options using these sources have been implemented at household and community levels. Alternative safe water options at household level include accessing water from safe HTWs, using sanitary protected dug wells, rainwater harvesting and using filtered or solar disinfected surface water. Such options at community level include hand DTW, motorized DTW with overhead reservoir and stand posts, rainwater harvesting, infiltration gallery/well and PSF (Abedin and Shaw 2013; Ahmed et al. 2002).

For arsenic removal from groundwater, a number of treatment technologies are in use in Bangladesh. At household level, these include inter alia passive sedimentation, rice husk arsenic removal unit, one bucket treatment unit, two bucket removal unit, Steven’s technology, Shafi filter, Sono 3-kolshi filter, activated alumina and solar oxidant (Mallick and Das 2003). Arsenic removal unit (ARU), Steven’s technology, Harbauer technology, bio-solution to arsenic problem and micro-biological process are suggested at community level (Mallick and Das 2003). Arsenic removal efficiency and unit cost of each of these technologies are also available. Besides these, Adarsha filter, Granet home-made filter, Alcan enhanced activated alumina, Tetra Hedron, ion exchange resins, Rajshahi University/New Zealand iron hydroxide slurry, and solar oxidation and removal of arsenic (SORAS) are among the household level arsenic removal technologies commonly used in arsenic affected areas (Abedin and Shaw 2013; Ahmed et al. 2002).
Technical effectiveness and sustenance of a few arsenic mitigation technologies are given in Table 2. There are both advantages and disadvantages of each technology (see Ahmed et al. 2002). Sustainability of some of these technologies was assessed in Sharmin (2008) using a set of 14 indicators related to technological, hydro-geological, economic, social and environmental aspects. DTWs were found to be the most sustainable technology, but are generally out of affordability of the rural people. Inauen et al. (2013) also found a high acceptance of piped water supply and DTWs among their users in the arsenic affected areas. DTWs are also highly resilient under most expected climate change conditions (Howard et al. 2010). Larger, utility-managed piped supplies are potentially highly resilient because of human resources and access to finance. Though people’s perception about dug well water was found to be good, finding a suitable location for its installation was hard (Sharmin 2008). Rainwater was found to be less acceptable due to its lesser taste than groundwater. Similarly, people did not feel comfortable with the PSF water. The best water quality and taste were from the Sidko filter as it effectively removed both arsenic and iron. In fact, household arsenic removal filters were among the most regularly used options (Inauen et al. 2013). However, a high installation cost and an unavailability of spare parts and skilled masons appeared to be the barriers for its sustenance. Apart from the unavailability of the technology and its spare parts, the long time required to get the water treated from the Sono unit is a discouraging factor for its wider uptake. Iron clogging generated in the reservoir and stagnant water in the chamber of an arsenic-iron removal plant (AIRP) were the discouraging factors for the use of this arsenic removal technology. The sustenance of a technology was also found to be related with its ownership and cost-sharing mechanism involved. In cases where there was no sharing of operation and maintenance cost of a technology among its users, the technology lacked proper maintenance and ultimately failed. In more than 80% of the cases in which there was a cost sharing mechanism in place, the functioning of the technology sustained.

The suitability of alternative water supply options is also area specific and depends on water quality, water availability throughout the year, installation cost, and ease of operation and maintenance (Alam and Rahman 2010). For example, as an easily available technology, but still capable of providing water of adequate quality, PSF was found to be the most attractive among the local people of Satkhira, Khulna, Bagerhat and Jessore in the coastal region (Islam and Mohammad 2013). Its maintenance cost was also found to be moderate.

Deep aquifers separated from shallow contaminated aquifers by impermeable layers are generally considered as a dependable source of arsenic-safe water. The present evidence also suggests that the chances of contamination of such deep aquifers are very low (Ravenscroft et al. 2013). As such, the arsenic mitigation strategies have been shifted from using dug wells and arsenic removal filters to other options such as tapping geologically targeted aquifers (Bhattacharya et al. 2010). However, the deeper aquifers without any separating aquiclude are vulnerable to contamination in the long run, although they may initially produce arsenic-safe water (Ahmed et al. 2002).

After installation of an alternative safe water option, its continuous monitoring is necessary at least for a few months because people are accustomed to using tube well water and may find the alternative option more complicated (Jakaria et al. 2003). Caretakers’ training and community participation are essential for sustainability of the water supply options. Desalination plant is expensive in terms of its capital as well as operation and maintenance costs, but it provides water of better quality in a large volume. Its commercial viability also exists (Islam and Mohammad 2013), but needs institutional support for operation and maintenance. Similarly, piped water supply needs institutional support to cover capital cost. If these two technologies can be operated using solar energy, the operation and maintenance cost would go down. Filter media of the desalination plant needs to be made available in the local market where iron is present in groundwater in addition to salinity and arsenic. MAR also has potential for scaling up as its cost is relatively low (Sultana et al. 2015). However, a number of challenges including the availability of suitable sites, management of
chemical and biological clogging and disinfection of recovered water are to be overcome in making this technology sustainable.

Table 2. Technical effectiveness and sustenance of some arsenic mitigation technologies

<table>
<thead>
<tr>
<th>Options</th>
<th>Characteristics</th>
<th>Technical effectiveness</th>
<th>Sustenance</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pond sand filter</td>
<td>Can remove bacteria from surface water by filtering it through a large tank filled with sand and gravel; Requires frequent washing for high turbidities; Fish culture is another limitation</td>
<td>2</td>
<td>High in coast</td>
<td>Jakaria et al. 2003</td>
</tr>
<tr>
<td></td>
<td>Microbial contamination of PSF water was high</td>
<td></td>
<td></td>
<td>Alam and Rahman 2010</td>
</tr>
<tr>
<td></td>
<td>Easily available and provides water of adequate quality</td>
<td></td>
<td>Attractive to the people of Satkhira, Khulna, Bagerhat and Jessore</td>
<td>Islam and Mohammad 2013</td>
</tr>
<tr>
<td></td>
<td>Only 6% of PSF-treated water was coliform-free</td>
<td></td>
<td></td>
<td>Kamruzzaman and Ahmed 2006</td>
</tr>
<tr>
<td>Rainwater harvesting</td>
<td>Rainwater can be stored in tank without being contaminated by bacteria</td>
<td>3</td>
<td>Least used</td>
<td>Inauen et al. 2013; Jakaria et al. 2003</td>
</tr>
<tr>
<td></td>
<td>43% of water samples were microbial contaminated</td>
<td></td>
<td>Medium in both coast and barind</td>
<td>Alam and Rahman 2010</td>
</tr>
<tr>
<td></td>
<td>Does not cover the demand for whole year; High cost of installation and operation</td>
<td></td>
<td></td>
<td>Islam et al. 2009</td>
</tr>
<tr>
<td></td>
<td>Subject to microbial contamination</td>
<td></td>
<td>Ideal for Bangladesh due to plenty of rainfall and ease of use</td>
<td>Islam et al. 2009</td>
</tr>
<tr>
<td>Dug well</td>
<td>If a dug well is protected properly, it may provide water of an acceptable bacteriological quality.</td>
<td>4</td>
<td>Least accepted</td>
<td>Inauen et al. 2013; Jakaria et al. 2003</td>
</tr>
<tr>
<td></td>
<td>Microbial contamination of dug well water was very common; 40% of dug well water exceeded the Bangladesh standard</td>
<td></td>
<td>High in Charghat; low in other places</td>
<td>Alam and Rahman 2010</td>
</tr>
<tr>
<td>Saofi filter</td>
<td></td>
<td>1</td>
<td></td>
<td>Jakaria et al. 2003</td>
</tr>
<tr>
<td>Three pitcher filter</td>
<td></td>
<td>4</td>
<td></td>
<td>Jakaria et al. 2003</td>
</tr>
<tr>
<td>Surface water filter</td>
<td></td>
<td>4</td>
<td></td>
<td>Jakaria et al. 2003</td>
</tr>
<tr>
<td>Sidko plant</td>
<td></td>
<td>5</td>
<td></td>
<td>Jakaria et al. 2003</td>
</tr>
<tr>
<td>TSF</td>
<td></td>
<td>5</td>
<td></td>
<td>Jakaria et al. 2003</td>
</tr>
<tr>
<td>Activated alumina filter</td>
<td></td>
<td>5</td>
<td></td>
<td>Jakaria et al. 2003</td>
</tr>
<tr>
<td>Desalination plant</td>
<td>Small-scale plant using reverse osmosis method consumes limited energy and costs around BDT. 30,000</td>
<td>5</td>
<td>Medium</td>
<td>Basar 2012</td>
</tr>
<tr>
<td>Piped water supply</td>
<td></td>
<td>5</td>
<td>Generally high</td>
<td>Inauen et al. 2013</td>
</tr>
<tr>
<td>Deep HTW</td>
<td>Only 7% of water samples were microbial contaminated</td>
<td>5</td>
<td>Generally high</td>
<td>Alam and Rahman 2010; Inauen et al. 2013</td>
</tr>
</tbody>
</table>

Note: A higher score in the third column indicates a higher effectiveness.

6. CONCLUSIONS

The synthesis of available literatures and information, and the analysis of groundwater level, use, recharge and quality indicate that the declining groundwater level is a threat to drinking water supplies in the barind and hilly areas both at present and in the future. Recharge is not a constraint for the rest of the HtR areas in the coasts and offshore islands, haors and chars. However, the
quality of groundwater, in particular arsenic, salinity, iron and manganese, is a major threat to safe drinking water supplies in these areas.

A number of options based on both alternative water sources and water treatment technologies are in practice in the HtR areas, in particular in the coasts, hills and salinity affected char areas. These multiple options are expected to continue at least in the near future. However, tapping targeted aquifer, piped water supply and desalination plant are among the emerging options for drinking water supply.

There are a number of constraints and barriers in the sustenance and uptake of the treatment based drinking water technologies. Ownership, unit cost, local availability and ease of operation and maintenance are among the principal factors affecting their sustained use. Measures should be taken to overcome these barriers.

Adaptive management, based on a principle of learning by doing, with monitoring of groundwater quality (salinization and arsenic mobilization) and level (mining), and regulation of groundwater use for agricultural and industrial purposes can be among the future sustainable management strategies.

A number of government organizations including BMDA, BADC, DPHE, BWDB, WARPO, Department of Environment and local government agencies are involved in groundwater extraction, monitoring and regulation. There are overlaps in organizational jurisdiction and mandates among these public agencies. They work in isolation without a common groundwater vision. More importantly, there are no unified national network and protocol for groundwater monitoring. Also, there is no national groundwater database in Bangladesh. These are urgently needed within a coherent institutional setup.

ACKNOWLEDGEMENTS

This manuscript is prepared based on a research project titled ‘Groundwater resources development in Bangladesh: Contribution to water supply and constraints to sustainability’ funded by the Federal Department of Foreign Affairs, The Embassy of Switzerland, Swiss Agency for Development and Cooperation.

REFERENCES


World Bank (2010) Implications of climate change for fresh groundwater resources in coastal aquifers in Bangladesh. South Asia Region
