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Sustainable Groundwater Management
Lessons from Practice

Case Profile Collection Number 17

Managing the Sustainable Development of Groundwater for "Arsenic-Safe" Water Supplies in Bangladesh

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Widespread arsenic contamination of shallow groundwater is a critical issue affecting the provision of safe drinking water in Bangladesh. Alternatives to groundwater are mainly derived from surface water sources, which carry the risk of bacteriological contamination and require treatment facilities which are often beyond the operational capacity of rural communities. The GW-MATE is advising on the technical and hydrological options to obtain 'arsenic-safe' groundwater and identify strategies to provide it for piped rural and urban water-supply. The work provided a key input to the development of guidelines for the use of groundwater and for building a regulatory framework for long-term sustainable management of the 'arsenic-safe' aquifers.

ORGANIZATIONAL ACRONYMNS

BAEC	*Bangladesh Atomic Energy Commission*
BAMWSP	*Bangladesh Arsenic Mitigation Water Supply Project*
BUET	*Bangladesh University of Engineering and Technology*
BWSPP	*Bangladesh Water Supply Program Project*
BWSD	*Bangladesh Water Development Board*
DoE	*(Bangladesh) Department of Environment*
DPHE	*(Bangladesh) Department of Public Health Engineering*
IAEA	*International Atomic Energy Agency*
MLGRDC	*(Bangladesh) Ministry of Local Government, Rural Development & Cooperatives*
NAMIC	*National Arsenic Mitigation Information Center*
WARPO	*Water Resources Planning Organization*
WSP	*(World Bank) Water-Supply& Sanitation Program*

Background to Support

- The shallow groundwater of Bangladesh is widely contaminated with arsenic above the WHO Guideline Value (10 ppb or ug/l), and also above the Bangladesh National Standard of 50 ppb. Since its discovery in the early 1990s a major effort has been made to improve understanding of arsenic occurrence in groundwater, and its public health and socio-economic impacts, as well as to develop and implement mitigation measures.

- The World Bank, together with other donor agencies, is providing the Bangladesh Government with strong support in its efforts to scale-up the provision of 'arsenic-safe' water from selected sources via piped distribution systems, which has been identified as the most cost–effective solution even in rural areas given the high density of villages and new rural growth centres.

- The World Bank support has been channeled through the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP, 1998-2006) and the Bangladesh Water Supply Program Project (BWSPP, 2004-2009), which focuses on promoting rural and urban piped water-supply development through enhanced private-sector participation. This profile also draws on the results of the World Bank-WSP Study on Arsenic Contamination of Groundwater in South & East Asian Countries – Towards a More Effective Operational Response (2005).

Occurrence and Screening of Arsenic in Groundwater

- The elevated arsenic concentrations in shallow groundwater are of natural origin, and result from the mobilization of solid-phase arsenic from the sediments of the aquifer matrix. The mechanisms of arsenic mobilization are still not fully understood, but in recent years there has been a major advance in hydrogeochemical understanding. It is generally agreed that the most important process is the release of arsenic absorbed on iron oxides under extreme reducing (anaerobic) conditions, although other processes may be involved including modification to the natural groundwater flow regime associated with groundwater resource development for agricultural irrigation.

- Despite improved understanding of the occurrence and distribution of soluble arsenic in shallow groundwater, there remains some uncertainty including the very large spatial variability in arsenic concentrations within the affected areas, even over lateral distances of less than 100 m. Hence predictability of groundwater arsenic concentrations at the local scale is still poor and blanket testing of individual wells is needed to take immediate decisions on the level of risk associated with individual tubewells, on their acceptability as a source of domestic water-supply and the approach to the design of mitigation measures.

- Groundwater quality screening from tubewells in arsenic-affected areas started under the BAMWSP with support of various donor agencies, international organization and NGOs. All data generated is

Table 1: Status of arsenic contamination from screening of shallow hand-pump tubewells

DIVISION	POPULATION (million)	ESTIMATED No. TUBEWELLS	TUBEWELLS TESTED	PROPORTION CONTAMINATED (%)*
Barisal	3.954	88,321	81,333	45.8
Chittagong	13.304	889,685	878,137	62.5
Dhaka	18.371	1,691,247	1,644,981	25.1
Khulna	12.263	996,096	989,643	28.1
Rajsahi	12.027	1,007,043	982,704	10.5
Sylhet	4.943	166,694	159,472	12.3

* *contaminated to above Bangladesh National Standard of 50 ppb*

stored in the National Arsenic Mitigation Information Center (NAMIC) and made available through reports and a website (www.bwspp.org). The current (2007) status of the arsenic contamination in shallow tubewells is summarized in Table 1, which clearly shows the very large scale of the problem.

Identification of Aquifers at Risk

- The aquifers at greatest risk of containing high-arsenic groundwater in Bangladesh are the recent (Quaternary) alluvial and deltaic sediments deposited by the Ganges-Brahmaputra-Megnha river system, which are characterized by highly-reducing conditions associated with very low hydraulic gradients and sluggish groundwater movement. These sediments occur as the surficial layer covering large parts of Bangladesh and are the reason for such a widespread groundwater arsenic problem in the country (Figures 1 & 2).

Figure 1 : Spatial distribution of groundwater arsenic contamination in Bangladesh (BGS, 2001)

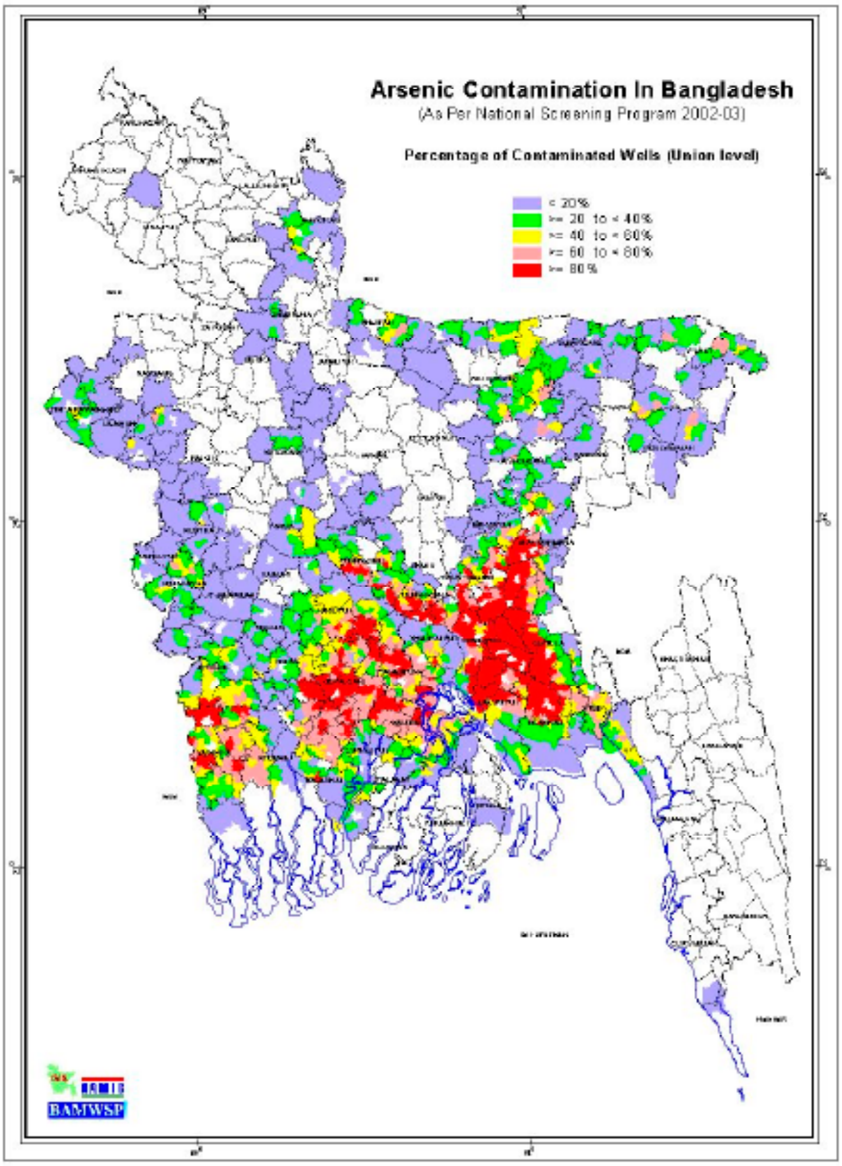
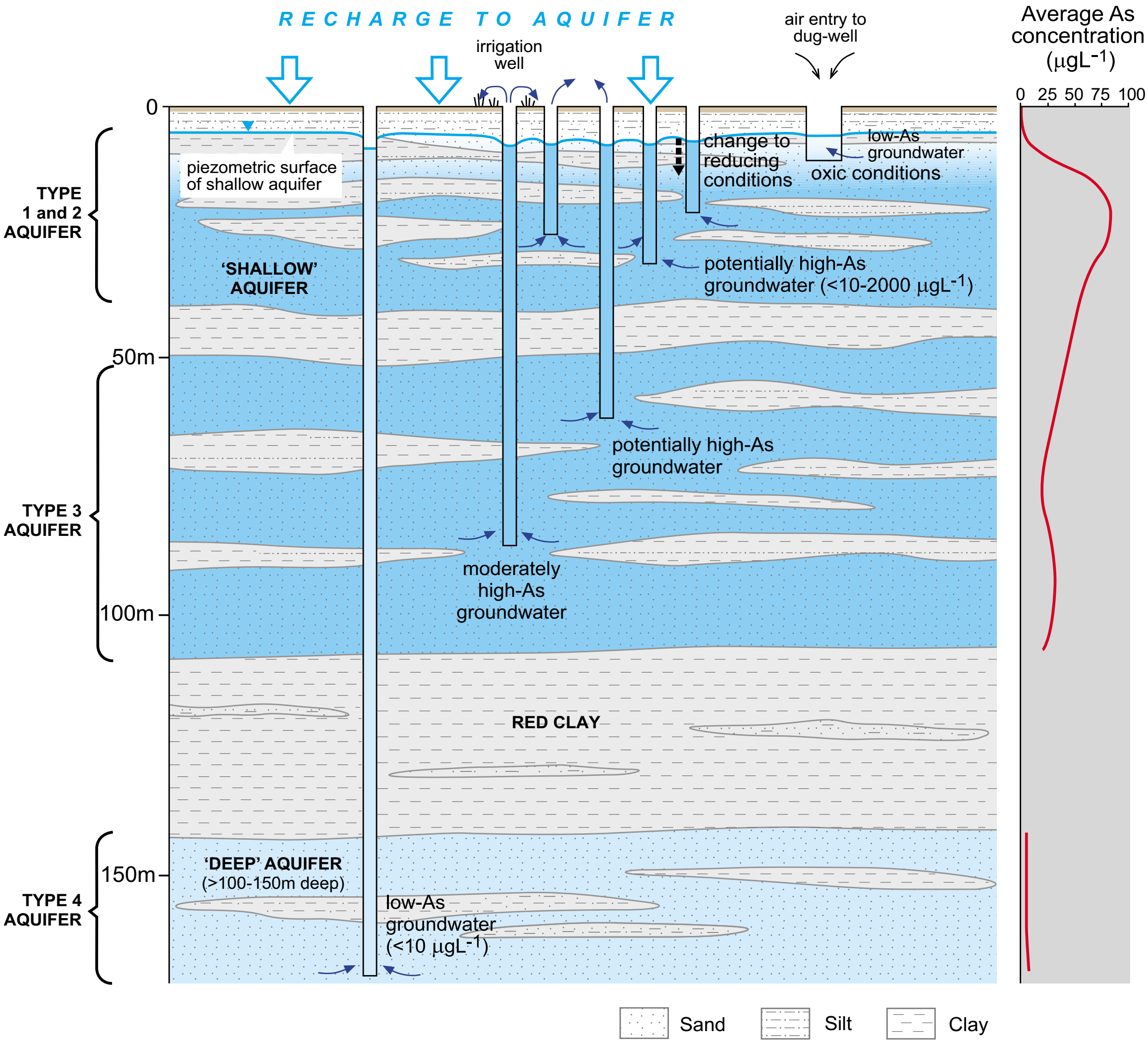


Figure 2: Typical sedimentary sequence underlying extensive areas of Bangladesh with an indication of the variation of groundwater arsenic concentration with depth (BGS, 2001)



- Since discovery of the groundwater arsenic problem in the early 1990s, a number of major in-depth hydrogeological studies have been carried out (Appendix A), a Bangladesh Groundwater Task Force formed, and an International Workshop on Arsenic Mitigation organized in January 2002. One important result was the presentation of a new classification of aquifers based on the age and type of their sediments, which provides a logical basis for characterizing arsenic contamination of groundwater and for identifying mitigation strategies. In this classification the arsenic contamination problem mainly affects the groundwater of the 'Type 1 Aquifer' which occurs up to depths of 100-150 metres (Table 2).

Table 2: Old and new classification of aquifer systems - (Bangladesh Groundwater Task Force, 2002)

DEPTH BASED *(old)*		SEDIMENTARY AGE-BASED *(new)*			LEVEL OF ARSENIC CONTAMINATION
aquifer name	Depth (mbgl)	aquifer name	Depth (mbgl)	Age (years)	
Upper or 1st	0-50	Type 1 and Type 2	0-100	<100	high
Main/Lower or 2nd	50-150				
(Red Clay Layer)	>150	Type 3	100-200	3,000	mainly free, but vulnerable
Deep or 3rd		Type 4 (deep aquifer)	>100-200	20,000	free and protected (where red clay present)

Other Groundwater Quality Issues

- Arsenic contamination is one of the main groundwater quality issues in Bangladesh, but not the only one. Other chemical and bacteriological water-quality concerns include the high levels of soluble iron (Fe) and managese (Mn), which are widely encountered in all aquifer types across the country, and high chloride (Cl) concentrations in the coastal region.

- The BAMWSP conducted a detailed water-quality testing program in Comilla, Barisal and Khulna Divisions (totalling some 1600 wells) to establish the overall groundwater quality of the deep (Type 4) aquifer. This confirmed some high Fe, Mn and Cl concentrations (Table 3), together with high Ba (barium) levels in a number of wells. These high Ba levels (in excess of the Bangladesh National Standard) were verified and given that this standard is 10 times higher than the WHO Guideline Value, the DoE will subject it to review during the next update. Bacteriological contamination, which is always a concern for surface water (pond and river) sources, is also widely found in groundwater from dug wells and some hand-pump tubewells, especially where their sanitary protection is inadequate.

Table 3 : Summary of results of BAMWSP groundwater quality survey (BWSPP, 2006)

DIVISION	NO. OF WELLS TESTED	NO. ABOVE BANGLADESH NATIONALSTANDARD		
		Fe (1 mg/l)	Mn (0.1mg/l)	Cl (600mg/l)
Barisal	1300	251	1	99
Comilla	32	7	1	3
Khulna	284	28	2	52

Water Resources Options for Drinking Water-Supply

- For the provision of 'arsenic-free' water via piped water-supply systems, a choice has to be made between the various water source options (Table 4) available in the general vicinity of the location of the village or rural development center (pourashava). The preferred option will largely depend on the cost of water, the acceptable level of operation and maintenance, the operator responsible for the system and the preference of water users.

Table 4: Comparitive summary of options for 'arsenic-free' water-supply sources

TYPE	COMPONENTS	ADVANTAGES	DISADVANTAGES
SURFACE WATER OPTIONS			
Surface Water Treatment System (SWTS)*	intake, treatment and conveyance	known technology quantity assured	conveyance may be long, intake works can be costly, seasonal water quality changes
Surface Water Infiltration System (SWIS)**	abstraction wells along river bank and conveyance	quality of water, (needs chlorination) easy O&M	needs permeable shallow formation and limited riverbed clays, little national experience
Surface Water Infiltration Gallery (SWIG)	infiltration galleries below riverbed	low cost, easy O&M	some quality concerns, no national experience
GROUNDWATER OPTIONS			
Shallow Tubewell (STW)	tubewell in arsenic free zones of Type 1, 2, 3, Aquifers	low cost, can be user-installed	site selection study required, conveyance may be long, some high Fe and/or Mn levels
	tubewell in arsenic affected zone of Type 1 Aquifer	readily available	as removal treatment required, O & M difficult at rural village scale
Deep Tubewell (DTW)	tubewell in Type 4 Aquifer	no treatment, high supply security, installation at community level	hydrogeological study needed, conveyance may be long, possibly other quality problems, high quality of well drilling and completion required

* *have additional disadvantage of high O&M costs especially for piped village water-supply schemes*

** *tested in Chapai Nawabganj and potential option to be investigated further (Appendix B)*

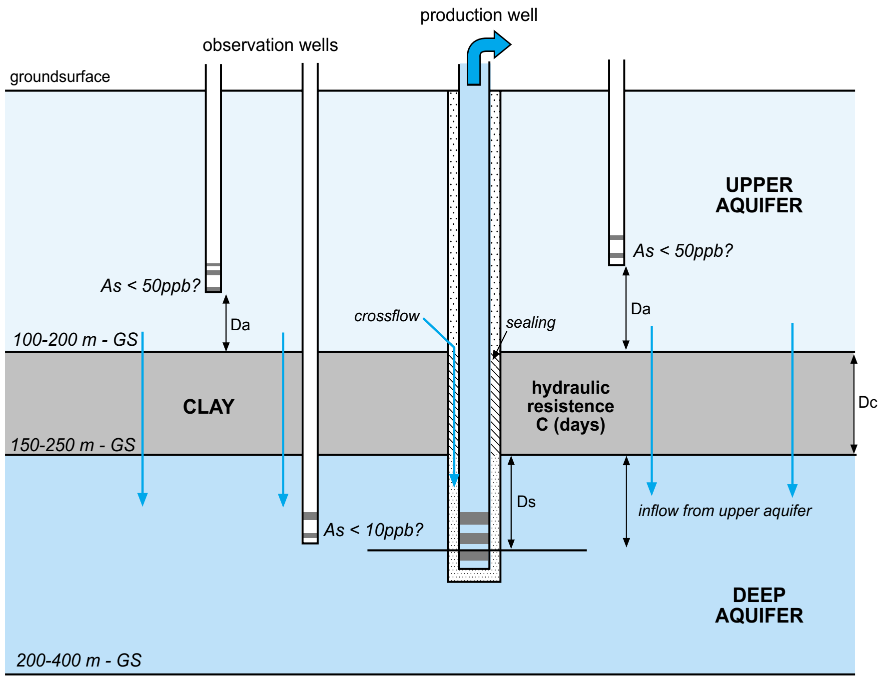
- Experience with piped water supply schemes shows that groundwater-based options are preferred by most communities, even in cases with high Fe and/or Mn levels requiring removal. But use of deep groundwater is constrained by the current strict policy guidelines which have to be followed as regards site selection and well construction.

Guidelines for Short-Term Supplies of 'Arsenic Free' Water

- Mitigation of arsenic-affected groundwater supplies follows two tracks : (a) arsenic removal at household level or community level and (b) provision of 'arsenic safe' water sources. There is a wide range of treatment technologies available to remove arsenic from contaminated water and these have been summarized by the World Bank-WSP (2005).

- The National Policy for Arsenic Mitigation (2003) recommends that surface water, if available, should have preference over groundwater in the development of new primary drinking water sources. Where groundwater has to be used there should be proper guidance to ensure the pumping of 'arsenic safe' water, and existing guidelines include protocols for :
  - deep tubewell construction in arsenic-affected areas
  - water-quality surveillance for rural water-supply options (DPHE)
  - water quality sampling and testing (BAMWSP)
  - groundwater investigations for rural piped water-supply schemes (BWSPP) (Figure 3).

Figure 3: Guidelines for groundwater investigations to supply rural piped schemes



STEP	ACTIVITIES	OUTPUTS	CONCLUSIONS/DECISIONS
1	• collection of data of existing wells in a grid of 10 km^2 : including lithological logs, well depth, water quality, abstraction rates	• location map • total abstraction • groundwater quality information	presence and estimated thickness of clay layer and As values in upper aquifer
2	• drilling of deep tubewells • preparation of lithological description • water sampling and analysis • measuring groundwater level before hand-pump installation	• borehole profile showing thickness of clay layer and sediments in deep aquifer • groundwater quality	BWSPP advise on next step depending on clay thickness and As value of water
3	• drilling of 1 hand-pump tubewell in upper aquifer (50mm) • preparation of lithological description • water sampling and analysis • measurment of groundwater level before hand-pump installations	• As level in upper aquifer • pressure difference between aquifers	BWSPP advise on next step depending on observed As levels and piezometric head difference BWSPP approval needed for drilling deep tubewell
4	• drilling production well (350mm) • lithological logs • well development and completion • groundwater quality test	• safe yield estimation • monitoring requirements	approval of safe yield and monitoring requirements by BWSPP

- The unregulated exploitation of the shallow aquifer already poses a growing threat to the sustainability of this groundwater resource. Groundwater quality in this aquifer is not only affected by arsenic contamination but also increasingly by anthropogenic pollution hazards from intensive use of on-site sanitation and from other pollution sources. Shallow groundwater also exhibits a declining water-table in areas of intensive groundwater irrigation – a trend which may accelerate as a result of reduced recharge in some climate change scenarios which imply longer dry periods and reduced riverflows.

- With surface water and shallow groundwater under increasing stress both in terms of quality and quantity, the deep aquifers in Bangladesh will become increasingly important as a source of 'arsenic free' and 'quality safe' drinking water for the growing population. The deep aquifers, although little developed to date in most parts of the country, also give rise to management concerns regarding groundwater quality and quantity. Groundwater level decline is already taken place in the Greater Dhaka area, due to unregulated abstraction and in the coastal region due to large-scale abstraction for irrigation. In both instances, greater difficulty and cost in providing safe drinking water result, with increasing social hardship.

- Groundwater development from the deep aquifer is urgently needed to provide 'arsenic safe' water, but if such development is unmanaged it could lead to resource degradation. An effective management strategy (based on sound hydrogeological understanding) will be needed to control the changes in groundwater flow and quality. The management strategy must also include the shallow aquifer and guide the mitigation of current problems.

- In line with the Bangladesh National Arsenic Policy, the BWSPP supports efforts to increase understanding of arsenic contamination by the characterization, mapping and monitoring of the deep aquifers (which are generally arsenic free) and to build a groundwater management and regulatory framework for the safe exploitation of these aquifers. Specific activities include:
  - cooperation with BAEC/IAEA to investigate the use of isotope studies in the characterization of deep aquifers (Appendix C)
  - data collection from BWSPP tubewells to broaden knowledge on base of deep aquifer
  - development and introduction of new technologies such as riverbank infiltration schemes (SWIS), in-situ iron/arsenic removal, modern geophysical methods for groundwater mapping and high quality PVC pipes for well construction
  - drafting groundwater legislation and setting-up regulatory framework
  - capacity building for DPHE and BWSPP staff
  - support for initiation of National Groundwater Mapping & Management Project.

Management and Regulation of Groundwater Development

- **Legal Framework**

  Water legislation in Bangladesh relates mainly to water resource development in different sectors: Irrigation Act (1876), Embankment & Drainage Act (1952), Inland Water Transport Authority Ordinance (1958) and the Bangladesh Water & Power Development Boards Ordinance (1972). Other enacted water legislation includes the Water Resources Planning Act (1992) and the Water Supply & Sewerage Authority Act (1996). A draft Water Resources Act has been prepared to replace the Water Resources Planning Act (1992) but is not yet enacted.

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- **Groundwater Management**
  The Groundwater Management Ordinance (1985) is designed to support groundwater development for agricultural production (eg. by providing water well spacing guidelines) – but this has never been workable and is presently suspended. The Ordinance does not take into account other uses and users, and leaves the legal position of groundwater used for domestic/industrial purposes in doubt. New legislation should include the possibility of declaring special groundwater management and protection areas, and provide for issues such as the registration of drillers, permits for water well drilling and groundwater abstraction control. A new Groundwater Management Act should be consistent with existing policies and strategies such as the :
  - National Policy for Arsenic Mitigation
  - National Water Management Plan
  - National Water Policy (NWPO)

- **Groundwater Rights**
  In the absence of a Water Resources Act there is no formal system of water rights or regulatory instruments for water use and allocation at present, and customary rights are less strongly developed than in many countries. The preparation of a regulatory framework has started with the preparation of protocols for:
  - installation of deep tubewells in arsenic-affected areas
  - quality surveillance for rural water-supply options.

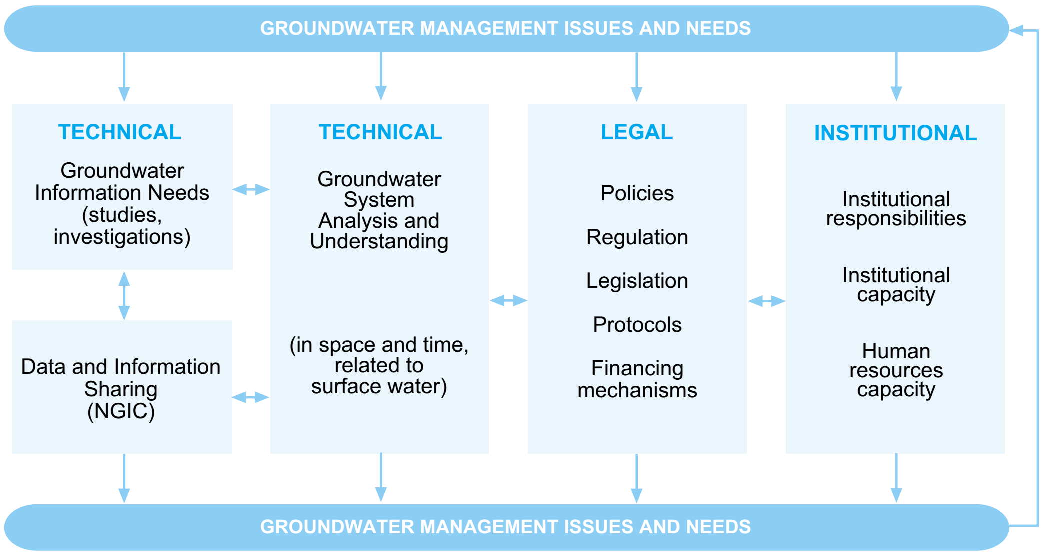
  These protocols need further refinement but form a good basis for the formulation of a national regulatory framework for groundwater resources.

- **National Groundwater Management Initiative**
  The overall responsibility for policy and planning is with WARPO under the Ministry of Water Resources, but that for water resource development is with the BWDB and MLGRDC. The BWDB is also responsible for regulation, but their mandate is not well defined and activities are not well coordinated with the other agencies.

- The key agencies relating to groundwater have recognized the need for more effective groundwater management and regulation, and shared this opinion in a consultation meeting of February 2006 and a follow-up stakeholder meeting of May 2007. This latter meeting was structured around a proposed groundwater management framework (Figure 4) – and there was a strong consensus for a national approach to groundwater management in which all the main agencies and stakeholders work together supported by effective regulatory mechanisms. Some of the other key messages from the meeting included :
  - the need for coordinated action is hence essential (especially since Bangladesh has the highest tubewell density in the world) and can be achieved through cooperation between the main water management institutions, but should also include universities and other private sector stakeholders and NGO's

- WARPO should take the lead in this process but a strong coordinated support from the entire water sector is needed for the successful implementation of this important task
- cooperation should focus around the full sharing of data and information
- a regulatory framework is the prerequisite for effective groundwater management
- deep groundwater should be reserved for drinking water supply.

Figure 4: Proposed groundwater management framework for Bangladesh



Appendix A : Recent Publications and Reports on Arsenic in Bangladesh Groundwaters

Groundwater Task Force (2002); Report of the Groundwater Task Force; Government of the People's Republic of Bangladesh, Ministry of Local Government, Rural Development & Co-operatives; Local Government Division, Dhaka July 2002

Islam, N.M. and Uddin, Md. N. (2002); Hydrogeology and Arsenic Contamination in Bangladesh. Theme paper 1 of the International Workshop on Arsenic Mitigation in Bangla Desh, Dhaka 14-16 January, 2002, Local Government Division, Ministry of LGRD@Co-operatives, Government of the Peoples Republic of Bangladesh

Aggarwal Pa.o. (2000); Report of Isotope Hydrology of Groundwater in Bangladesh: implications for Characterisation and Mitigation of Arsenic in Groundwater. Report prepared within the IAEA-TC project BGD/8/016, Dhaka, December 2002

Islam, N.M. and Uddin, Md. N. (2002); Hydrogeology and Arsenic Contamination in Bangladesh. Theme paper 1 of the International Workkshop on Arsenic Mitigation in Bangla Desh, Dhaka 14-16 January, 2002, LocaL Governement Division, Ministry of LGRD@Co-operatives, Government of the Peoples Republic of Bangladesh

BGS and DPHE (2001); Arsenic Contamination of Groundwater in Bangladesh, British Geological Survey and Department of Public Health Engineering, Government of Bangladesh, Final Report, Volume

JICA, (2002); The Study of Groundwater Development of Deep Aquifers for Safe Drinking Water Supply to Arsenic Affected Areas in Western Bangladesh; Draft final report, Kokusai Kogyo Co. ltd Mitsui Mineral Development Engineering Co Ltd.

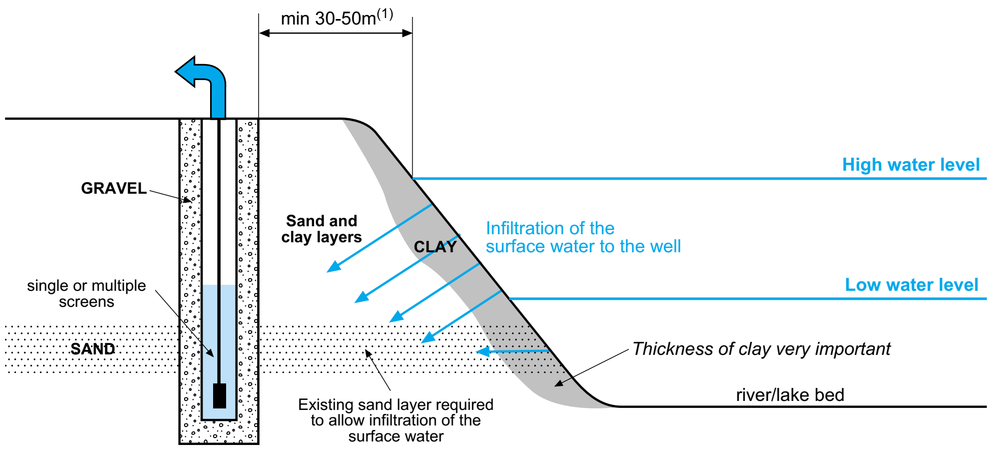
Hussain, Md. M and Abdullah, S.K.M. (2001) Geological Setting of the Areas of Arsenic Safe Aquifers; Ministry of LGRD&Co-operatives, Local Government Division, Groundwater Task Force, Interim Report no. 1, Dhaka (October 2001)

World Bank/WSP (2005) Towards a More Effective Operational Response (Arsenic Contamination of groundwater in South and East Asian Countries) PDF available on http://siteresources.worldbank.org/INTSAREGTOPWATRES/Resources/ArsenicVol1_WholeReport.pdf

Ahmed, M.F. and C. M. Ahmed, eds. 2002 Arsenic Mitigation in Bangladesh, Dhaka, Bangladesh ; Progressive Printers

Rahman, A.A and P. Ravenscroft (editors), 2003 Groundwater Resources and Development in Bangladesh; Background to the Arsenic Crisis, Agricultural Potential and the Environment. University Press LtD, Dhaka

Appendix B : Design of a surface water infiltration scheme



NOTE
(1) This distance is required to avoid contamination of the abstraction point. It depends on the grading of the various sand/clay layers

An alternative option for development of safe water from the shallow aquifer is the abstraction of groundwater near to rivers. River water generally contains no arsenic and if the major part of the pumped water originates from the river it may provide a safe source of potable water. Surface water infiltration schemes (also named: induced riverbank infiltration schemes) are applied in many countries including the water supply of large cities such as Berlin and Prague.

The main design parameters for a SWIS are:

- a minimum distance of the well from the river in order to secure that the pumped water is bacteriologically safe (usually a 60 days travel time of the water is used as a design parameter)
- the entry resistance between the river and the aquifer, which largely determines the inflow of river water (and hence the technical feasibility)
- well distance and well yield (the most cost effective combination of the two)

The design parameters can be determined from:

- the drilling of shallow observation wells to check water quality, groundwater flow and the type of sediments (including the thickness of the clay layer along the river bank)
- the drilling of a production well for a constant discharge test (72 hrs) during which the groundwater levels are observed in the observation wells
- evaluation of the test and calculations with a groundwater model to simulate the scheme for different design options

Currently a pilot project is carried out under the BAMWSP to test the feasibility of a SWIS in Chapai Nawabganj along the Mohananda River. A total of 14 observation were drilled and one production well. A 72 hrs constant discharge test was carried out in March and the results are now being evaluated. The results will be used to design a pilot and demonstration scheme on the premises of the Chapai Nawabganj Water Works Compound. The scheme will be ready by the end of August and will be used for monitoring/demonstration and provide additional water to the Chapai Nawabganj water supply scheme.

Appendix C : A groundwater isotope study to map ‘arsenic-free’ sources of groundwater

High arsenic concentrations in Chapai Nawabganj were first detected in the early 1990s and six out of nine production boreholes had to be abandoned. Presently, two main options for alternative water supply are being evaluated: treatment of surface water from the Mahanandan River or drilling of new production boreholes in arsenic-safe aquifer(s). An arsenic-free aquifer would provide a much cheaper alternative as water treatment after production would normally not be required. The IAEA and its local counterpart, the Bangladesh Atomic Energy Commission, have teamed with the World Bank to use isotope techniques to supplement the investigations for selecting arsenic free groundwater sources.

Groundwater investigations and isotope study

Investigations of arsenic-free groundwater included the drilling of more than 40 observation wells and 2 production test wells (see figure 1a), a comprehensive water sampling and analysis program, water level observations, and two aquifer tests. The study revealed a distinct difference in sediments between the eastern part (grey sands) and western part (brown sands) of the area. The groundwater in the eastern part of the aquifer (grey sands) is free of arsenic. Along the transition towards the brown sands, arsenic concentrations increase distinctly from <10 ppb to >50 ppb (see figure 1a).

To further investigate the origin of the groundwater and to determine the nature of hydraulic connection with the grey and the brown sand portions, groundwater samples from observation and production wells and the river were analyzed for the stable isotopes of oxygen and hydrogen as well as the radioactive hydrogen isotope, tritium.

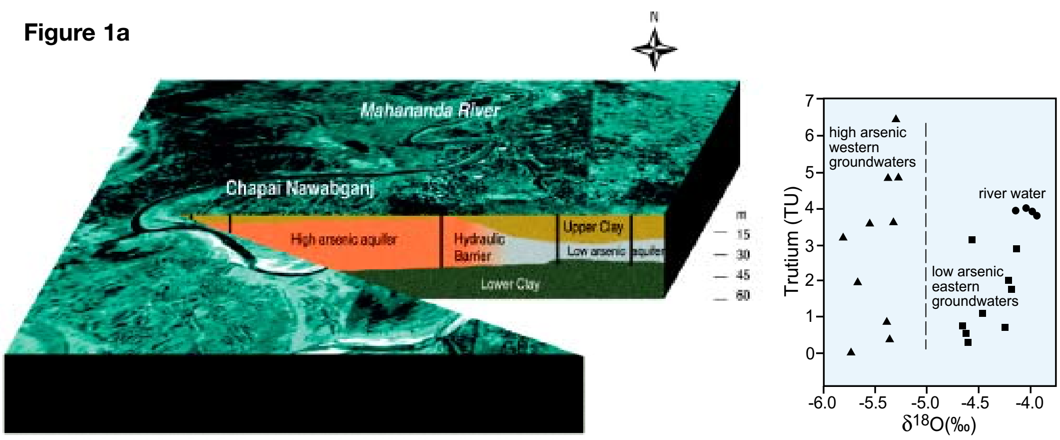
The isotope analysis confirmed: Conclusions with respect to arsenic mitigation

- that groundwater in the grey sands in the western part would provide a source of arsenic-free water without the danger of it being contaminated in the future.
- the inflow of river water into the aquifer in the western part, indicating the possibility of designing river bank infiltration systems for arsenic-free water supply in this area.

Lessons learned

A lesson learned from the Chapai study is that the use of isotopes from the beginning of the study would have been cost effective for the entire investigation. Such a study would have provided the general picture of the groundwater flow regime at an early stage and therefore a much smaller number of observation wells and hydraulic testing would have been needed for the detailed analysis.

Figure 1a



Publication Arrangements

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