

Sustainable Groundwater Management Lessons from Practice

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Mitigation of Arsenic Contamination in Drinking Water-Supplies of Bangladesh — the Case of Chapai Nawabganj

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Widespread naturally-occurring arsenic contamination of shallow groundwater is a major challenge in relation to safe drinking-water provision in Bangladesh – and the most obvious alternative of surface water sources carries the risk of serious microbiological pollution and necessitates treatment facilities often exceeding local financial resources and operational capacity. GW•MATE support has focused upon reviewing the technical options for the provision of arsenic-safe groundwater and on developing implementation strategies for rural and urban water-supply. This Case Profile summarizes the development of a rational strategy for long-term mitigation of the arsenic water-supply problem in the large town of Chapai Nawabganj, where excessive arsenic concentrations in the urban water-supply were detected in the mid-1990s. This experience may serve as a model for other similarly situated towns.

GENERAL BACKGROUND

Scope of Support

- Shallow groundwater in Bangladesh is widely experiencing arsenic contamination of geogenic origin, with concentrations both above the WHO guideline value for drinking-water (10 µg/l) and the Bangladesh national standard (50 µg/l). Since its discovery in the early 1990's, a major effort has been made to improve the understanding of arsenic occurrence in groundwater and its public-health implications, and to develop and implement mitigation measures.
- The World Bank, together with numerous bilateral donor agencies, has provided the Government of Bangladesh with strong support for its efforts to provide arsenic-safe water-supplies, with an emphasis on new sources feeding piped distribution systems both in urban areas and in rural areas with a high village density. The World Bank-support has been channeled through the Bangladesh Arsenic Mitigation Water-Supply Project (BAMWSP) during 1998-2006 and the Bangladesh Water-Supply Program Project (BWSP) during 2004-2010.

Severity of Arsenic Contamination

- The aquifers at risk are Quaternary alluvial and deltaic sediments associated with the Ganges-Brahmaputra-Meghna river system, which have naturally very slow groundwater movement and reducing conditions with elevated soluble iron and potentially excessive soluble arsenic concentrations. These sediments form the land surface across large parts of Bangladesh (Figure 1).
- Since the discovery of the 'groundwater arsenic hazard' in the early 1990s, a number of in-depth hydrogeological studies have been carried out, a Bangladesh Groundwater Task Force formed and an International Arsenic Mitigation Workshop organized in January 2002. One significant result was the presentation of a new aquifer classification based on age (and type) of their sediments, which is more logical for the characterization of arsenic contamination and identifying mitigation strategies (Table 1).

Figure 1: Spatial distribution of groundwater arsenic contamination in the 'upper aquifer' of Bangladesh (data from National Screening Program 2002-3)

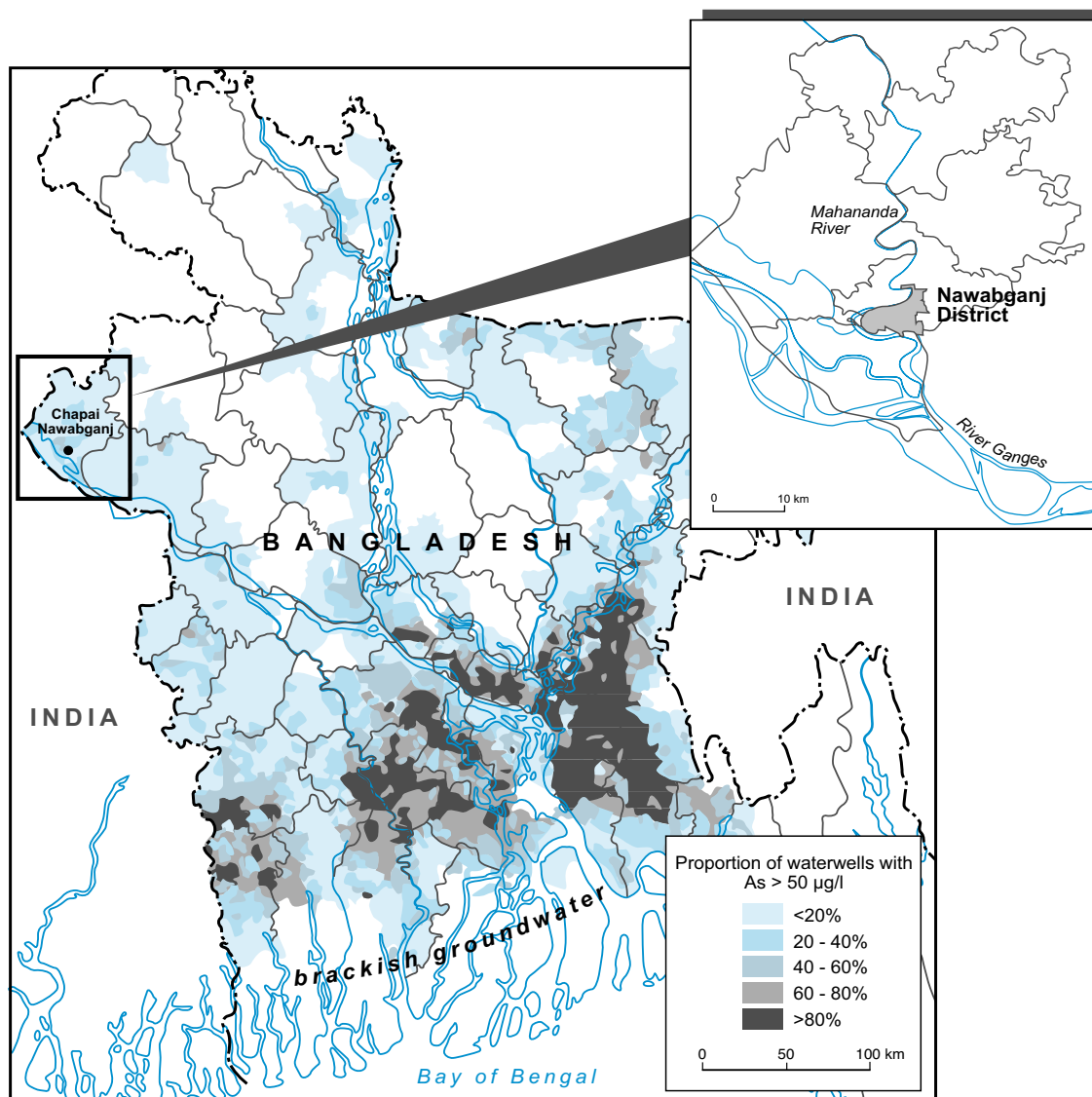


Table 1 : Old and new classification of aquifer systems

OLD CLASSIFICATION (based on aquifer depth)		NEW CLASSIFICATION (based on aquifer age)			ARSENIC CONTAMINATION STATUS
aquifer name	depth (mbgl)	name	depth (mbgl)	age (years)	
Upper 1st Aquifer	0-50	Type 1 & Type 2 Aquifer	0-100	<100	widespread high arsenic concentrations
Main 2nd Aquifer	50-150				
Deep 3rd Aquifer	>150	Type 3 Aquifer	100-200	3,000	mainly arsenic-free, but potentially vulnerable
		(Red Clay Layer) Type 4 (Deep Aquifer)	>100-200	20,000	arsenic-free and protected where red clay is present

- Groundwater quality screening from hand-pump tubewells in arsenic-affected areas commenced under the BAMWSP in 2002, with support of various donor agencies, international organizations and INGO's. All data generated is stored in the National Arsenic Mitigation Information Center (NAMIC) and made available through periodic reports and via website (www.bwssp.org). By 2007 a large amount of waterwell analytical results had been collected which showed that in the Chittagong, Barisal and Dhaka Divisions respectively (with a total population of 35.7 million) 63%, 46% and 25% respectively of a very large sample of tubewells tested recorded unacceptable arsenic concentrations. The problem spread to other divisions also but more patchily.

Approaches to Mitigation

- In 2004 a national policy to confront the 'groundwater arsenic problem' was defined, which provided the basis for the creation of an Arsenic Policy Support Unit (APSU) and Implementation Plan for Arsenic Mitigation (IPAM) guided by a national committee. However, momentum was not sustained and by 2008 the APSU had disbanded, but in 2009 the national policy was revised and a new initiative taken to revive the IPAM.
- The policy recommends taking a different approach to the provision of arsenic-safe domestic water-supply according to local circumstances, in which the main approaches can be summarized as follows :
 - awareness raising in rural areas only to use those shallow hand-pump tubewells confirmed as arsenic-safe (and marked by green labelling) or sand-filtered water from ponds for drinking-water purposes
 - provision of arsenic-removal devices at household or community level (mostly through the administration and supervision of NGO's) in rural areas where no shallow hand-pump tubewells were found to be arsenic-safe
 - drilling of deep hand-pump tubewells in the coastal zone (where the shallow arsenic- safe groundwater is mainly unfit for drinking due to high salinity levels)
 - construction of piped water-supply schemes (for urban and rural multi-village centers) from arsenic-safe sources (deep groundwater, river-bank infiltration or treated surface water).

THE EXAMPLE OF CHAPAI NAWABGANJ

Historical Evolution

- Chapai Nawabganj is town of around 200,000 population located in the west of Rasjahi Province on the bank of the Mohanandan River (Figure 1). Its water-supply system was constructed in the early 1990's and comprised 9 production waterwells in the shallow aquifer (40-60 m depth) with a total abstraction capacity of 13 Ml/d. In 1995, following the discovery of 'patchy' arsenic contamination, 6 waterwells had to be taken out of production, causing a sharp decline in available water-supply to almost 3 Ml/d.
- No further action was taken until 2000 when Chapai Nawabganj was included in the BAMWSP and 2 additional production waterwells were drilled, bringing the capacity to produce arsenic-safe water to 5 Ml/d. Other technical activities implemented under the BAMWSP included rehabilitation the distribution network, renovation of an elevated distribution reservoir, regeneration of some of the abandoned waterwells and drilling of 2 further waterwells near the Mohanandan River. Thus by 2006, production capacity was increased to almost 8 Ml/d, servicing about 40,000 people through 4,000 house connections and 200 stand-posts. However, the rest of the population (approaching 160,000) was still dependent on shallow hand-pump tubewells and hand dugwells, some of which were not arsenic-safe.
- Under the BWSP a major water-supply expansion (of up to 15 Ml/d) was proposed, with operation through a concessionaire management contract. The choice of potential sources for this new water-supply was typical of that available to many urban and rural growth centers in central Bangladesh :
 - arsenic-free surface water from the Mohanandan River
 - shallow waterwells to induce bank infiltration from the same river
 - arsenic-safe groundwater from the shallow aquifer (up to 50 m bgl)
 - arsenic-free groundwater from the deep aquifer (below 150 m).
- In Chapai Nawabganj a groundwater and surface water investigation program was conducted to compare the feasibility of the above options and to test different investigation methods. Many shallow observation wells plus 2 production waterwells were drilled, and a large amount of data collected (Table 2) – but whilst pre-existing borehole logs suggested the existence of an arsenic-free aquifer from 160 m depth, no budget was available to drill deep boreholes. However, the option of investigating and using deep groundwater at a later stage has not been discounted.

Shallow Groundwater Assessment

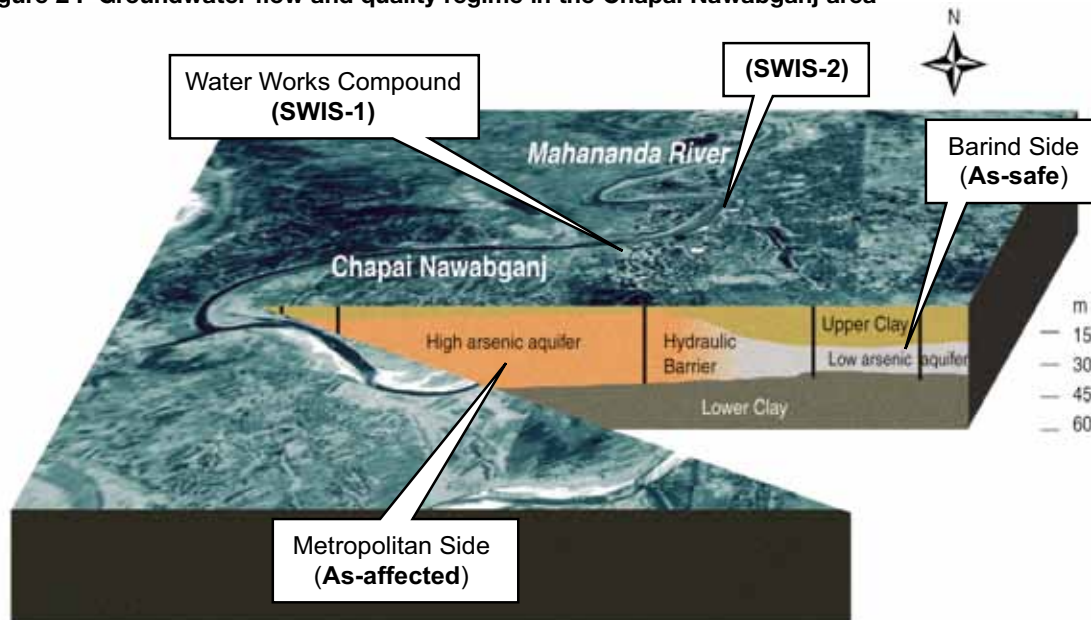
- The data collected from the shallow observation wells and production waterwells was sufficient to draw-up a detailed conceptual model of the groundwater flow and quality regime in the shallow aquifer (Figure 2), from which it was concluded that :
 - across the district there is a marked difference in aquifer lithology between the Barind (eastern) side (grey sands) and Metropolitan (western) side (brown sands), but no evidence of any related hydraulic discontinuity
 - all existing production waterwells abstract from the shallow sandy aquifer, which is underlain by a thick clay layer from 40 m bgl ground surface

Table 2 : Scope of groundwater and surface water investigation and data collection in the Chapai Nawabganj district

ACTIVITY	SCOPE OF MEASUREMENTS
<i>Observation Well Drilling</i>	<ul style="list-style-type: none"> • 16 observation wells at water-works (WW 1-16) • 8 testing wells at various locations along river bank (RB 1-8) • 5 testing wells in Dariapur area (D 1-5) • 35 observation wells across entire district (CN 1-35) • all waterwells located and levelled by GPS
<i>Production Water-well Construction & Testing</i>	<ul style="list-style-type: none"> • 2 production wells – at water-works (SWIS -1) and 1500 m west (SWIS - 2)
<i>Water Level Observation</i>	<ul style="list-style-type: none"> • river-level weekly during 2004-05, together with groundwater level in adjacent observation well • groundwater levels in 16 water-works wells in March 2004 at time of surface-water infiltration test • groundwater level observations in CN 1-35 and WW 1-16 in March & October 2005 • groundwater levels in 5 observation wells bi-weekly for 1 year
<i>Water Quality Sampling & Testing</i>	<ul style="list-style-type: none"> • river water tested bi-monthly in 2004 at 5 locations • groundwater quality of RB 1-8 & D 1-5 tested bi-weekly in 2004; • groundwater quality of observation wells CN 1-35 tested twice • groundwater quality of SWIS - 1 & 2 wells tested every 3 months

- groundwater on the Barind side of the shallow aquifer is arsenic-free, but along a line of transition concentrations increase rapidly from < 10 ppb to > 50 ppb in the Metropolitan portion (except for wells located along the river like SWIS-1)
 - soluble iron levels in groundwater are generally high, especially in the Metropolitan side where they range from 1-10 > 1 µg/l whilst on the Barind side they vary from <1 µg/l up to 4 µg/l
 - groundwater is almost stagnant in the western area, but regional flow is occurring at a very low rates in the eastern part and discharging to the river
 - groundwater levels fluctuate seasonally by 3 m, increasing to 5 m in the vicinity of the river.
- Two aquifer pumping tests were conducted to evaluate the properties of the shallow aquifer – the permeability (hydraulic conductivity) of the sands is estimated to average around 13-15 m/d, however the transmissivity is higher in the Metropolitan than Barind side (320 m²/d compared to 200 m²/d) mainly as a result of the larger saturated aquifer thickness (25m compared to 12 m).
 - IAEA-Isotope Hydrology Section undertook isotope analysis (¹⁸O-²H and ³H) on groundwater from the shallow aquifer (Figure 3) – corroborating the above conclusions and providing significant new information :
 - groundwater in the Barind portion originates from recharge in the east but is mixed with infiltrating rainwater (or river water) along its flow path
 - groundwater on the Metropolitan side is of local origin and a mix of rainwater and river-water, confirming the hydraulic connection from the river and nearby ponds to the aquifer
 - the distinct difference in stable isotope signature between the two areas confirms a hydraulic barrier probably caused by a subtle geological unconformity in the sedimentary deposits.

Figure 2 : Groundwater flow and quality regime in the Chapai Nawabganj area



Surface Water Related Options

- Chapai Nawabganj is located on the banks of the Mohanandan River, which is perennial but has a wide variation in water-level (> 10 m) between wet and dry season. The groundwater chemical quality is good, except for its elevated and variable soluble iron content. Turbidity concentrations are quite high during the wet season and its use would also require consistent disinfection due to the presence of significant fecal microbiological pollution. Technically, any water-supply intake should be designed such that it can operate under the large river-level fluctuations, although bank stability and erosion are not a major concern.
- An alternative option for development of safe water from the shallow aquifer is the abstraction of groundwater near to rivers (Figure 4). 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. Induced riverbank infiltration schemes are used in many countries, including the water supply of large cities such as Berlin and Prague.

Figure 3 : Isotope signatures of different groundwaters in the Chapai Nawabganj area

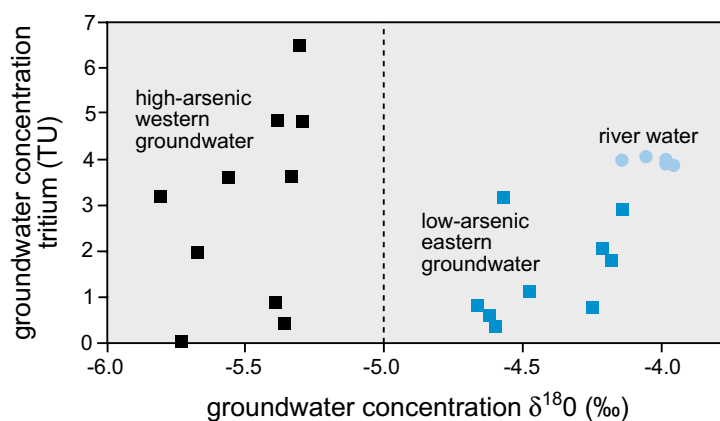
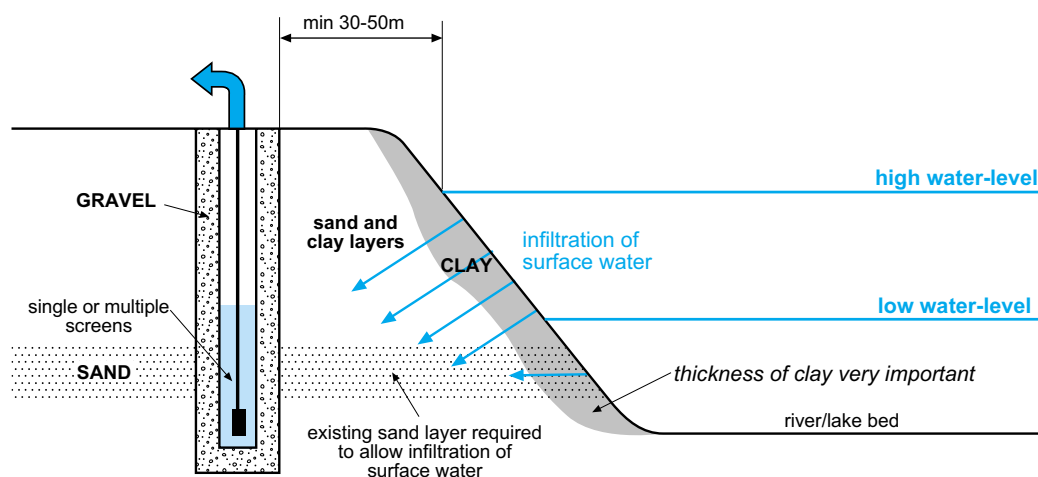


Figure 4 : Design of an induced surface-water infiltration scheme



- The new production wells drilled near the Mohanandan River (SWIS-1 & SWIS-2) derive part of their groundwater by ‘induced river-bank infiltration’, which provides a generally arsenic-safe source. The aquifer test results and water-level monitoring were used to simulate groundwater flow through numerical modelling, and suggest that about 30% (in the dry season) and up to 60% (in the wet season) of water pumped from SWIS-1 originates from the river, with travel times of 5-40 days depending on season – and suggest that a waterwell 50 m from the river pumping 1 Ml/d will obtain 35% of its yield from the river.
- The main parameters determining technical feasibility and design for this type of scheme are:
 - a minimum distance from waterwell to river for a microbiologically safe supply (usually 60-day travel time)
 - the entry resistance between the river and the aquifer, which largely determines the inflow of river water
 - sufficient aquifer transmissivity to provide adequate waterwell yield.

These design parameters can be determined from:

- the drilling of shallow observation wells to check groundwater quality, flow direction and the stratigraphy of sediments (including the thickness of the clay layer along the river bank)
 - the drilling of a trial production well for a constant-discharge aquifer (3–day) test
 - evaluation of the data with a groundwater model to simulate different design options for the scheme.
- A demonstration scheme on the premises of the Chapai Nawabganj Water-Works Compound has been developed on this basis and is also providing additional water to the town water-supply scheme.

Way Forward

- The various investigations in Chapai Nawabganj have led to the following conclusions:
 - the Metropolitan portion of the shallow aquifer is the most productive but cannot be further exploited for drinking water-supply because of serious arsenic contamination and extremely high soluble iron content, but the eastern Barind portion is arsenic-free and production waterwells in this area can produce 0.5-0.7 Ml/d and be spaced 700-1000 m apart to limit mutual interference – a wellfield in this part of the aquifer would probably deploy about 25 waterwells to supply 15 Ml/d, with the disadvantage that a major part would have to be located outside the district boundary

- induced riverbank infiltration (via a line of shallow waterwells 20 m from the river) would be the most reliable option in the Metropolitan portion, with operational monitoring to check soluble As and Fe levels.

Lessons for National Mitigation Program

- A detailed investigation and monitoring program, including isotope analysis, is useful to provide the technical foundation for managed development of sustainable arsenic-safe water-supplies for large towns. Systematic aquifer pumping tests are important to evaluate shallow aquifer properties and potential for river-bank infiltration. If there is evidence of a deeper aquifer (which is likely to be arsenic-free), it is recommended that a deep trial production waterwell should be included in the investigation program.

Further Reading

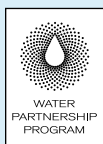
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Publication Arrangements

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