

SZÁNTÓ et al.

---

**37th WEDC International Conference, Hanoi, Vietnam, 2014****SUSTAINABLE WATER AND SANITATION SERVICES  
FOR ALL IN A FAST CHANGING WORLD****Decision-support for arsenic- and salt-mitigation in  
Bangladesh: the ASTRA approach**

*G. L. Szántó, D. van Halem, L. C. Rietveld, S. Olivero, A. Adams, D. C. Roy,  
J. Barendse, K. Baby, M. M. Hoque & J. W. Dogger, Hungary*

**REFEREED PAPER 2045**

---

*Bangladesh faces a growing water crisis. Limitations to safe water access arise from the widespread pathogenic contamination of its surface waters, the severe arsenic contamination of its aquifers and the growing salinity in the country's coastal regions. Appropriate water supply methods are identified for some of these contexts, it is challenging to select resilient water supply solutions for the low-income, rural areas of Bangladesh. The ASTRA tool is developed to support the identification of potentially appropriate drinking water methods and to aid their implementation in this context. It can be seen as the combination of a multidisciplinary sourcebook and a decision-support instrument. This paper outlines the main mitigation routes as the (i) targeting of contamination-free groundwater, (ii) treatment of arsenic- and salt-contaminated aquifers and (iii) utilization of non-groundwater sources. The paper also describes the tool-inventory and the context factors applied to determine functional ranges of the included water supply methods.*

---

**A growing water crisis in Bangladesh**

Bangladesh faces a growing water crisis. Being one of the most densely populated countries in the world, it has over 150 million inhabitants living on 147,570 km<sup>2</sup>. Poverty indicators estimate that 43.3 % of the population earns less than USD1.25 pppd and as much as 57.8% suffers from multidimensional poverty (UNDP, 2013). In the recent past, the increasing population pressure and the related environmental load resulted in a growing pathogenic contamination of surface water streams. The continued use of these water sources led to frequent epidemics that shifted focus to the use of ground- and rainwater sources (Field et al., 2011). At present, still about 79 % of all drinking water is estimated to be withdrawn from diverse groundwater sources (FAO-AQUASTAT, 2013).

In 1993, the naturally occurring arsenic was discovered in the groundwater (Kinniburgh and Smedley, 2001). Today, the extent of exposure to dangerous concentrations of arsenic in drinking water is estimated to affect 25-45 million Bangladeshi inhabitants (based on exposure levels of >50 µg L<sup>-1</sup> and >10 µg L<sup>-1</sup>, respectively). Saline intrusion – as a result of climate change – is another growing problem, mainly manifesting in the coastal areas of Bangladesh. This phenomenon does not only affect drinking water sources, but irrigation as well. With that, its effect goes beyond the water sector and affects the country's food sovereignty as well.

Currently, attempts to reduce risk of arsenic- and salt-contamination make use of a small range of technological methods. Deep-tube wells and rainwater harvesting technologies are the most frequently used safe water options. Deep wells enjoy widespread popularity because at depths in excess of 80m most aquifers are free of significant contaminations. Rainwater use is widespread as it is a renewable source of (largely) contaminant-free water. Unfortunately, both systems have significant bottlenecks that limit their use. Deep-tube well applicability depends strongly on local geology (Inauen et al., 2013). The potential of rainwater harvesting methods are indicated to have low acceptance rates. Similarly to HWTS devices, this is motivated by the fact that rainwater methods require considerable efforts from the users both during the implementation and the application phases.

So far, technological implementations were only partially successful in abating the arsenic- and salt-contamination problems. In order to increase resilience of current mitigation methods and ensure the proper implementation of new ones, this study outlines a novel decision-support tool (ASTRA) that focuses on the identification of potentially appropriate, arsenic- and salt-mitigating water methods for diverse Bangladeshi contexts.

### **Decision-support approaches for increased sustainability**

The implementation and use of appropriate methods is a key prerequisite in achieving an improved water sector. The selection of appropriate technological methods is relatively easy in wealthy, developed countries where the dominantly centralized water supply creates a high level of uniformity. In these sectors, technology selection is straight-forward because the small number of choices are simplified through regulations and engineering standards. Maintenance of existing systems is made efficient, as the uniformity ensures that most parts are interchangeable and easy to obtain.

Such an infrastructural grid is limited in most developing countries. Even where standardized water supply methods are widespread (e.g. a centralized water supply chain), these are often vulnerable to limitations in technical, financial and organizational infrastructure. As a result, strongly infrastructure-dependant solutions are largely omitted and their application is limited to the middle- and high-income communities in larger cities. In their place, decentralized, often on-site methods are the primary choices for water access. The diversity of decentralized methods implies that their efficient use depends largely on the context where they are applied in. In practice, reliable information on the functioning of on-site methods is often missing. To tackle this problem, several knowledge bases (compendia) were developed in the recent past. While some of these compendia are developed to ensure (multidisciplinary) knowledge dissemination regarding the contained technologies (e.g. the SSWM (2012) or Akvopedia (2011) portals), others include both dissemination and decision-support functions. Decision-support tools can be defined as instruments that offer information to aid the understanding of method applicability in predefined contexts. Examples to such tools include the EAWAG compendium (Tilley *et al.*, 2008) or the online WaterCompass (PRACTICA *et al.*, 2013).

### **Methodology**

The research for the development of the ASTRA decision-support tool focused on the acquisition, analysis and synthesis of information regarding water methods applied in arsenic- and salt-mitigation in and outside of Bangladesh. The data acquisition considered three main sources, namely (i) academic publications (monographs, reports and papers), (ii) (practical) water supply/treatment project reports and other output and (iii) interviews with Bangladeshi and international water experts. Publicly available, practical information on the quality of functioning of water supply methods proved to be scarce. Therefore data acquisition was partially achieved through open-ended interviews with local and international water experts (ASTRA, *in preparation*). The scope of analyzed methods contains

- best practice technologies involved in arsenic- and salt-mitigation in Bangladesh,
- sustainable technologies for arsenic- and salt-removal in an international, development-context,
- high-tech technologies potentially relevant for Bangladeshi arsenic- and salt-mitigation, and
- promising arsenic- and salt-removal methods still in development.

The selected and methods were subject to analysis according to a number of context factors and their options. These factors were chosen after analysis of existing technology knowledge bases and decision-support tools. The proposed factors and their sub-categories were then cross-checked with water experts on quality.

### **The ASTRA tool**

#### **Description of tool structure**

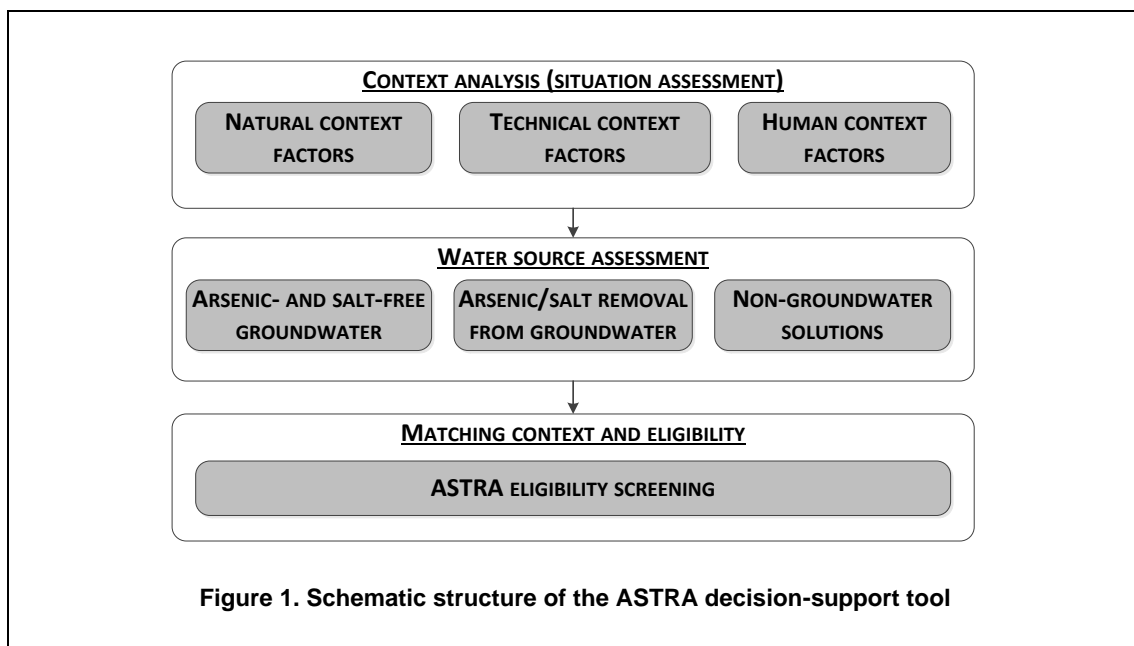
The ASTRA arsenic- and salt-mitigation approach (Figure 1) involves an eligibility screening of ‘best available technologies’ for the selection of resilient water supply and treatment solutions in the Bangladeshi context.

The first step of this approach involves the strategic analysis of the project or policy context for which one or more potential methods need to be identified. Extent of this assessment may vary depending on the specific goal of the method identification. In general, a few known traits of a project location or region may already be sufficient for the starting of the procedure. For a systematic context analysis, a total of 21 factors

were identified (Table 1). These factors were classified in three groups. These groups are meant to define the natural, human and technical context in which the technological method will need to function. Natural context factors are included as they determine the (largely) unalterable traits of the given situation. Human factors may be alterable (e.g. with behavior change campaigns), but any change is likely to require considerable efforts and time. In general, technical factors offer the most flexible traits of the project context. Determining as many as possible of the 21 factors forms the first stage (i.e., context assessment) of the ASTRA approach.

The second stage of the procedure is the viewing of the potential water supply and treatment method groups to identify one or more approaches that may be applicable. 25 source development, conveyance and treatment methods were grouped according to three mitigation approaches Table 2). These three method groups include

1. Arsenic- and salinity-free groundwater abstraction;
2. Treatment of arsenic- or salt-containing groundwater; and
3. Appropriate, non-groundwater solutions including surface and rainwater options.



The third stage of the tool considers the matching of the initially defined context factor options and the functionality of the included methods. This occurs with the support of the functionality matrices that are predefined for each method and contain the level of applicability of the method for each of the context options of the tool.

### The context analysis

Analysis of an affected area or project situation is a crucial first step in the determination of a proper response. Lack of a good understanding of the context in which a technological method is embedded may result in high failure rates and a repeated need for mitigation actions. There are numerous factors with differing importance that may describe a project context. An optimal tool reduces the complexity of analysis by limiting the analysis factors to elements with the greatest importance. This is a challenging task as it requires the identification of objective factors (perceived by everyone in the same way) and the assurance that the necessary information for those factors is likely to be available in most situations.

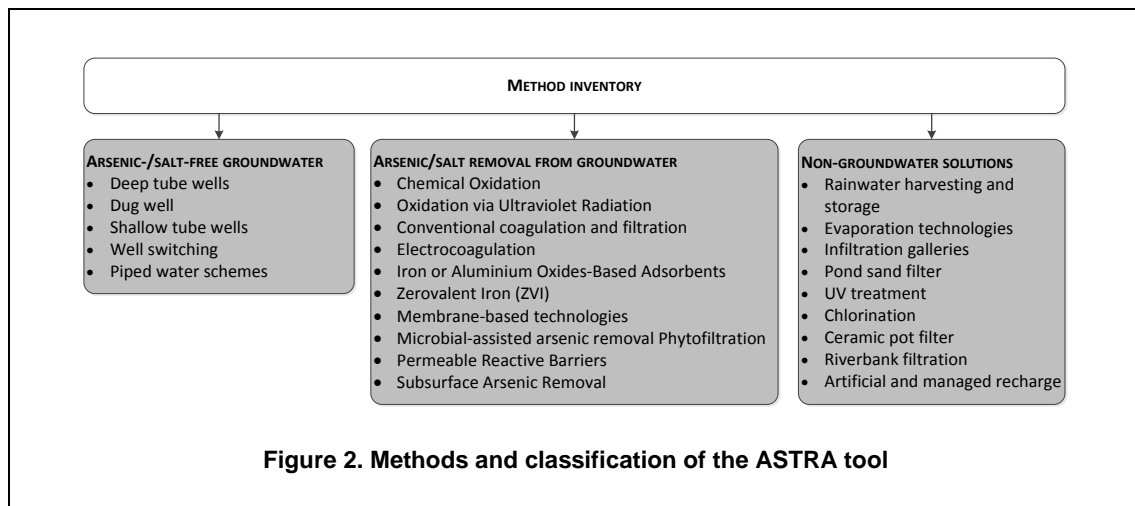
To offer an example, the level of willingness-to-pay is a crucial factor in assessing cost recovery and the rate of revenue from an implemented solution. However, such information is hard to define properly without executing extensive survey and research. For this reason, the ASTRA tool is designed to include natural-, human- and technological-context factors that are not only objective but are also identifiable in most situations. Only those factors are included that can support a meaningful classification.

<b>Table 1. Context criteria and their respective options</b>			
	<b>Criterion</b>	<b>Included options</b>	<b>Featured aspect</b>
<b>Natural context factors</b>	<b>Water source</b>	Surface, brackish, rain- and groundwater	Locality of water body
	<b>Water quality</b>	Arsenic, salt	Type of contamination
	<b>Ground formation</b>	Sand & gravel, clay formations, compacted formations, soft weathered rock and bedrock	Soil composition
	<b>Depth of water table</b>	0-8, 8-15, 15-40 and >40 m	Depth of water level
	<b>Flood danger</b>	Not affected, only flooded in extreme weather & annually affected by floods	Level of flood risk
<b>Human context factors</b>	<b>Type of community</b>	Densely populated urban; densely pop., low-income urban; moderately pop. urban, peri-urban, rural and rural-remote	Settlement type and population density
	<b>Type of location</b>	Settlement, agricultural and coastal	Type of location
	<b>Implementation scale</b>	Household, shared, small community, school or institution and large user group	Scale of sustainable dissemination
	<b>Preferred level of water delivery</b>	Household, shared, small community, school or institution and large user group	Connection level to water supply
	<b>Preferred management level</b>	Household, shared, small community, school or institution and large user group	Type and level of method managing
	<b>Energy available</b>	None, electricity grid, fuel generated, solar and wind energy	Possible means of powering device
	<b>Access to site</b>	On parcel, outside of household, <10 minutes to access, <30 minutes and >30 minutes	Means of accessibility to water point
<b>Technical context factors</b>	<b>Status in Bangladesh</b>	Widespread, known, little known, unknown	Level of embeddedness
	<b>System sophistication</b>	Labor-intensive, intermediate and technology-intensive	Labor-using or automated process
	<b>Water transport</b>	Manual, animal and motorized	Water transport options
	<b>Construction costs</b>	Negligible, <USD25, USD25-100, USD100-1,000 and >USD1,000	Costs of physical installation
	<b>Maintenance costs</b>	Negligible, <USD5 per month, USD5-100 per month and >USD100 per month	Costs related to O&M
	<b>Construction time</b>	None, a day, less than a week and weeks	Typical construction time
	<b>Level of expertise-O&amp;M</b>	Household, local technician, local government and external experts	Required level of skills in O&M
	<b>User acceptance</b>	No activity, limited extension, considerable extension and extensive campaign	Level of requirement to inform user about use

### Compendium of potential mitigation methods

Figure 2 contains the method inventory of the ASTRA tool. In the tool, each of the 25 methods contains a multidisciplinary description and a functionality matrix. In the matrix, each of the context factors are included and each of their options is evaluated according to the actual functioning of the relevant water method. Classification is done in four distinctive categories:

- Appropriate, indicating that the option is functioning properly in the viewed option;
- Appropriate with restrictions, indicating that the method may be suitable for the option, but it is likely to function sub-optimally;
- Not appropriate, indicating that the method is unlikely to function in a resilient way for that option; and
- Not relevant, indicating that the option does not influence eligibility of the viewed method.



### Matching of context and eligibility

The eligibility screening is in essence a multicriteria analysis<sup>1</sup> that offers an aggregated, multidisciplinary output on method eligibility. To offer an example, the choosing of groundwater as a water source in the tool would make all groundwater-abstracting methods ‘appropriate’ and all others ‘not appropriate’. (Whether a method is eligible for groundwater abstraction can be viewed in the respective functionality matrices of the methods.) When more factors are determined by the user, each factor is matched with each method’s matrix to finally offer an aggregate result where each method would be termed ‘appropriate’, ‘appropriate with restrictions’ or ‘not appropriate’. This eligibility output is kept simple in order to ensure that tool users can easily understand which method(s) fulfill their input requirements.

In an optimal scenario, a method may score appropriate for each factor, making it fully appropriate for the intended project context. More often, some of the viewed factors are likely to be only partially or non-appropriate. As a result of the simple matching, a clear indication on appropriateness is given as the user can immediately identify the specific factors that do not suit the intended project context. A viewing of the method description then offers a basic advice on the reason of limitation or ineligibility.

### Strengths and weaknesses of the ASTRA tool

The screening process is simple as it operates with a one-step multicriteria analysis. This simplicity offers a transparency that improves the understanding of method appropriateness. In this context, it implies that anyone using the tool can easily identify why a certain method is chosen to be eligible or not in a given context. Considering the complexity in a real selection process this is expected to contribute to the optimal decision-making process of the tool user.

The tool is designed to be accessible to all project stakeholders, including non-experts. A key strength of the concept is that it offers reliable information in an accessible format to aid the identification of potentially resilient methods. It is important to note that it does not remove the need of water experts in implementation projects; the tool only makes their work and the related knowledge transfer to other stakeholders more efficient. This is a crucial feature of the approach and it emphasizes that in reality no strategy can account for every local alteration in the functionality of a method. As the tool only offers an appropriateness screening, its output (the pool of potentially applicable methods) still needs to be assessed. This should

optimally occur in a multistakeholder setting, where the participants can view and evaluate the selected methods. For this task, several instruments are available (e.g. the WASHTech project tools (Olchewski *et al.*, 2012)).

The simplified screening process implies that the tool quality is primarily based on the quality of its content. In the ASTRA tool this is achieved through the using of peer reviewed and expert tested data and facts in both the description and the applicability of the included methods. Some of the contained information is liable to changes over time. This necessitates regular reviewing of the reliability of the tool, but it also implies that future methods can be included as well. As the tool offers a standardized description format, the new methods can be easily compared to the already included methods.

### Final remarks

The key features of this type of decision aid can be summarized as

- multidisciplinary format supports easy comparing of current and future methods,
- it contains an extensive, peer reviewed knowledge base of 25 arsenic- and salt-mitigation methods,
- accessible decision-support instead of decision-making: to aid responsible method selection,
- the output is applicable as a common knowledge platform in multistakeholder processes in the implementation phase of water projects,
- the tool and its content has the potential to reduce data scarcity on a crucial water challenge.

---

### Acknowledgements

The authors would like to extend their thanks for the financial support of the BRAC WASH II program.

---

### References

- AKVOPEdia (2011) *Akvopedia: Open source water and sanitation knowledge*. On: [http://www.akvo.org/wiki/index.php/Main\\_Page](http://www.akvo.org/wiki/index.php/Main_Page).
- Olschewski, A., Danert, K., Furey, S., (2012) *Technology Assessment Framework (TAF) and Guidance for Technology Introduction (GTI)*. Research Report Deliverable #3.2. Skat Foundation, Switzerland.
- FAO-AQUASTAT (2013) *UN-Water Country Brief – Bangladesh*. AQUASTAT Programme of the Food and Agriculture Organization of the United Nations. On: [www.fao.org](http://www.fao.org).
- Inauen, J., Hossain M.M., Johnston R.B., Mosler H.-J. (2013) *Acceptance and Use of Eight Arsenic-Safe Drinking Water Options in Bangladesh*. PLoS ONE 8(1): e53640.
- Kinniburgh, D.G., Smedley, P.L. (2001) *Arsenic contamination of groundwater in Bangladesh vol 2: final report*. BGS and Department of Public Health Engineering, Dhaka, Bangladesh.
- PRACTICA et al. (2013) *WaterCompass - multidisciplinary decision-support tool for drinking water method selection*. On: [www.watercompass.info](http://www.watercompass.info).
- SSWM (2012) *Sustainable Sanitation and Water Management toolbox*. On: [www.sswm.info](http://www.sswm.info).
- Tilley, E., Lüthi, C., Morel, A., Zurbrugg, C., Schertenleib, R. (2008) *Compendium of sanitation systems and technologies*. EAWAG, Duebendorf, Switzerland.
- UNDP (2013) *Human Development Indicators - Bangladesh*. A Human Development Report of the United Nations Development Programme. [www.hdr.undp.org](http://www.hdr.undp.org).

---

### Note

<sup>1</sup> [www.astradst.info](http://www.astradst.info)

**Contact details**

G. L. Szántó & A. Adams  
PRACTICA Foundation, Papendrecht, NL  
Tel: +31 786150125  
Email: [gabor.szanto@practica.org](mailto:gabor.szanto@practica.org),  
[alida.adams@practica.org](mailto:alida.adams@practica.org)  
www: [www.practica.org](http://www.practica.org)

Dipok Chandra Roy  
Practical Action Bangladesh, Dhaka, Bangladesh  
Tel: +880 28650439  
Email: [Dipok.Roy@practicalaction.org.bd](mailto:Dipok.Roy@practicalaction.org.bd)  
www: [www.practicalaction.org/bangladesh](http://www.practicalaction.org/bangladesh)

D. van Halem, L. C. Rietveld & S. Olivero  
Faculty of Civil Engineering and Geosciences,  
Delft University of Technology, Delft, NL  
Tel: +31 152789802  
Email: [D.vanHalem@tudelft.nl](mailto:D.vanHalem@tudelft.nl),  
[L.C.Rietveld@tudelft.nl](mailto:L.C.Rietveld@tudelft.nl), [S.Olivero@tudelft.nl](mailto:S.Olivero@tudelft.nl)  
www: <http://www.citg.tudelft.nl/>

J. Barendse  
WASTE Foundation, Gouda, NL  
Tel: +31 786150125  
Email: [jbarendse@waste.nl](mailto:jbarendse@waste.nl)  
www: [www.waste.nl](http://www.waste.nl)

M.M. Hoque  
BRAC, Dhaka, Bangladesh  
Tel: +880 29881265  
Email: [mofazzal.hoque@brac.net](mailto:mofazzal.hoque@brac.net)  
www: [www.brac.net](http://www.brac.net)

K. Baby & J.W. Dogger  
IRC Int. Water & Sanitation Centre, The Hague, NL  
Tel: +31 703044000  
Email: [kurian@irc.nl](mailto:kurian@irc.nl), [dogger@irc.nl](mailto:dogger@irc.nl)  
www: [www.irc.nl](http://www.irc.nl)

---