Institution: Queen's University Belfast

Unit of Assessment: 14 Civil and Construction Engineering

Title of case study: Removing Arsenic from Groundwater

1. Summary of the impact (indicative maximum 100 words)

A Queen's University team led by Bhaskar Sen Gupta installed the world's first chemical free water treatment plant in the arsenic belt of India to benefit rural people living on per capita income of less than 1 US$ a day. With nine facilities in India, Cambodia and Malaysia, more than 13,000 people are receiving their water supply from Subterranean Arsenic Removal (SAR) plants (www.insituarsenic.org). Many villagers who started using clean water from the community plants in 2008 have shown significant signs of recovery from chronic arsenicosis.

2. Underpinning research (indicative maximum 500 words)

Millions of people worldwide are chronically exposed to high levels of arsenic in water with a mortal risk of suffering from various forms of cancer; at least 137 million people in 70 countries consume arsenic laced groundwater due to shortage of safe drinking water (Wikipedia). The conventional technologies for arsenic remediation are based on 'pump and treat' method involving either adsorption or membrane processes. Such plants are expensive to run and have problems associated with waste disposal and maintenance. In contrast, Subterranean Arsenic Removal (SAR) or 'In-situ treatment' developed at Queen's University Belfast (QUB) neither uses any chemicals, nor produces any waste, making it a very low cost technology option for rural use. This pioneering research, for the first time established how arsenic can be removed without any use of chemicals in the aquifer zone by naturally occurring soil bacteria. This technology can replace expensive adsorption or membrane based processes where disposal of high-arsenic hazardous waste pose a serious problem. A very low operating cost makes the process affordable.

The work has been funded from 'concept to construction' by the EC (***grant 1***), World Bank (***grant 2***), British Council/DFID (***grants 3-5***) and Royal Academy of Engineering at different stages. The findings have been reported in a book edited by Sen Gupta et al. (***reference 1***) and other published papers (***references 2-4***). As a result, QUB has full access to eight operating plants in three countries for field data collection and further research. QUB has recently set up Research Centres in Calcutta and Kuala Lumpur to work closely with overseas partners, Bengal Engineering and Science University, National Metallurgical Laboratory, IEMS (TATA Steel) and University of Malaya (***grant 6***) for further developing the SAR technology and running training programmes.

<u>The innovative process (SAR)</u>

The technology is based on promoting the growth of arsenic oxidising bacteria in the aquifer, which in turn dissolves arsenic into sparingly soluble form and returns it to the soil under oxic conditions. The underground aquifer is turned into a natural biochemical reactor and adsorber, that removes soluble As along with Fe and Mn at an elevated redox value of groundwater (Eh> 300 mV in the oxidation zone), when dissolved oxygen concentration in the groundwater is raised above 4 mg/L. The oxidation processes are accelerated by the autocatalytic effect of the oxidation products and by the autotrophic micro organism. No sludge is produced in the process, maintaining normal permeability of the aquifer.

In order to ensure real life application of the arsenic remediation technology in the resource-poor areas, the following conditions were considered:

(i) Marginalised rural communities may not be able to pay more than 1 US$ for a month's potable water supply
(ii) They may not be able to pay for regular maintenance, chemical supplies, waste disposal and other recurring costs

(iii) The technology should ideally be waste-free.

All SAR plants are designed to produce safe drinking water (<10 µg arsenic) without the use of any chemicals/adsorbents/membranes and waste generation. Furthermore,

(i) All treatment plants can operate on electricity, solar or wind power, which make them suitable for use in remote areas with no access to grid power;
(ii) Plants have a very long life; submersible pumps can run for 25 years with very little maintenance;
(iii) Every single component used in the plant is available from local hardware shops.

The technology was developed by a consortium of Indian and European Engineers led by Bhaskar Sen Gupta in 2004-06. The initial research partners were Stuttgart University, Leiden University, Miguel Hernandez University from Europe and National Metallurgical Laboratory, Institute of Environmental Management and Studies and Ramakrishna Vivekananda Mission from India. QUB has been currently working with Royal University of Phnom Penh, Bengal Engineering and Science University, University of Malaya and National Metallurgical Laboratory of India for large scale implementation of the project. Current research facilities created by QUB in India and Malaysia are adequate to support this work in future.

International prizes recognising this research

(1) IChemE (UK) Ambani Prize for outstanding innovation in chemical engineering, York, 2009
(2) Times Higher Education Outstanding Engineering Research Team of the Year, London, 2010 (sponsor: BAE Systems, http://europe.nxtbook.com/nxteu/tsl/THE_awards2010/index.php#/26; BBC News, http://www.bbc.co.uk/news/uk-northern-ireland-11856751)
(3) Innovation Award for Remediation Technology, 'Environment and Energy Award', Birmingham, 2011 (http://www.sustainabilitylive.com/page.cfm/link=190)

The key achievement was summarised by the jury of the UK Environment and Energy Award where QUB prevailed over highly established companies in the award shortlist, Palladin UK Ltd, Adventus-Americas, Adventus-Europe and MAVA:

"The judges felt this was a highly innovative technology based upon a thorough understanding of the biogeochemical principles of Arsenic fate and transport in groundwater. It takes full account of the technical and financial constraints of the areas of the world where Arsenic groundwater contamination is a significant human health risk. The low tech nature of the installations coupled with the minimal waste disposal and energy requirements set the standard in sustainable remediation to which others should aspire."

3. References to the research (indicative maximum of six references)
(All describe the technology. The doi for three highlighted outputs is shown in bold.)

(1) Sen Gupta, B., Bandopadhyay, A., Nag, N.K. Low cost technology for in-situ treatment of groundwater (Book), Macmillan India, New Delhi, 2008; ISBN 023-063-639-X
(2) Sen Gupta, B., Chatterjee, S., Rott, U., Kauffman, H., Bandopadhyay, A., DeGroot, W., Nag, N.K., Carbonell-Barrachina, A.A., Mukherjee, S. A simple chemical free arsenic removal method for community water supply – A case study from West Bengal, India, Environmental Pollution, Vol 157, 2009, pp 3351-3353. **doi: 10.1016/j.envpol.2009.09.014**
(3) Carbonell-Barrachina, Á.A., Signes-Pastor, A.J., Vázquez-Araújo, L., Burló, F., Sen Gupta, B. Presence of arsenic in agricultural products from arsenic-endemic areas and strategies to reduce arsenic intake in rural villages, Molecular Nutrition and Food Research, Vol 53, 2009, pp. 531-541. **doi: 10.1002/mnfr.200900038**
(4) Hashim, M.A., Mukhopadhyay, S., Sahu, J.N., Sen Gupta, B. Remediation technologies for heavy metal contaminated groundwater, Journal of Environmental Management, Vol 92, 2011, pp 2355-2388. **doi: 10.1016/j.jenvman.2011.06.009**

International grants

(1) Bhaskar Sen Gupta, Coordinator, EuropeAid, 2004-2006, €438,906, "Low-cost technology for arsenic-poisoned water treatment".
(2) B. Sen Gupta, Chief Adviser to the WB Project DM0880, World Bank, 2008-2009, US$20,000 to QUB (total award US$200,000 shared by Indian and EU partners), "Arsenic removal from groundwater - experiment to delivery".
(3) B. Sen Gupta, PI, British Council, DelPHE Round 3, 2008-2011, £17,500 to QUB (total award £60,000 to Queen's and two Indian partners), "Capacity building for technological solution and training to improve groundwater resources management in arsenic affected areas of Eastern India".
(4) B. Sen Gupta, PI, British Council, DelPHE Round 5, 2010-2013, £60,000 shared by QUB and Royal University of Phnom Penh, "Training and capacity building to utilise groundwater resources in the arsenic affected areas of Cambodia".
(5) B. Sen Gupta, PI, British Council UKIERI, 2012-2014, £40,000 shared between QUB and BESU, India, "Assessment of effects of arsenic pollution on health in rural Bengal".
(6) B. Sen Gupta, CI; Professor M. A. Hashim, PI, University of Malaya, Kuala Lumpur (Grant nos: PV102-2011A and UM-QUB6A-2011), £100,000 (500,000 MYR - held at UM).
(7) B. Sen Gupta, PI, St Andrews University-ConocoPhillips, 2010, £50,000 to QUB, "Groundwater research for arsenic remediation".

These grants do not include costs of building work in India and other countries during implementation, to maximise health benefit. The total amount spent on building plants by QUB as the PI of ***grant 1*** is €200,000.

4. Details of the impact (indicative maximum 750 words)

The beneficiaries primarily include six villages (Merudandi, Purbapara, Gotra, Naserkul, Rangapur and Tepul – population 9000) in West Bengal (***sources 1, 2, 3***), two in Cambodia (Prey Veng & Kandal Provinces - serving 4000 people) and one in Malaysia (trial supply in place) and a small community in Lummi Island in the Washington State, USA (30 families, ***source 4***). The technology has already been accepted by three Government water agencies in India, Malaysia and Cambodia.

The impact is primarily provision of safer water at a low cost. Apart from benefitting hundreds of people directly, many communities are advised to set up their own plants through online support system created by the team (www.insituarsenic.org). Interested people from all over the world visit the group's website for more information (11112 hits during 15 January 2009 - 28 June 2013 and thousands of email queries). More than 300 people visit this website every month and ask questions about this technology using an on-line query.

Plants of 10,000 litre capacity based on the current design cost US$ 6000 (mains supply - India) and US$ 10000 (solar - Cambodia) respectively. Solar plants have no recurring operation cost while conventional plants cost US$ 1 to produce 10,000 litres of water. Recently a plant operating on solar power has been designed by QUB and installed by Royal University of Phnom Penh in Kandal Province of Cambodia which is prone to heavy floods. Such plants produce safe water even at the worst flood situations. All plants were set up by local plumbers and electricians from locally available components.

Dates of impact

The research that started at QUB as a matter of concept development with EU funding, was implemented for the first time anywhere in the world as full scale replicable technology in 2008 by the QUB personnel for supplying safe water to rural communities at a very low cost.

Between 12 June and 10 November 2008, Sen Gupta and his QUB team installed 6 community water treatment plants in West Bengal, India, close to the Bangladesh border (***sources 5, 6***). Further experimental plants were set up in Washington State (January 2011), Kota Bharu,

Malaysia (September 2011) and in the Prey Veng & Kandal Provinces of Cambodia (September 2011 & February 2012). The cleaner water had a remarkable impact on the affected population. Most people in an advanced stage of arsenicosis showed signs of recovery in less than a year [video clip (6.45 min, interview of the people starts after 3.5 min: http://www.youtube.com/watch?v=Bf-8wX-Y_Bc)]. Because the plants constructed are continuously operated, the impact is ongoing. The scale of the impact (e.g. numbers of people affected, outcomes in terms of health benefits, economic outcomes, lives saved, and quality of life) is described above, and summarised in Section 1.

Other value-added activities

Community training programmes, mostly in cities, since 2008 - seven in India; one each in USA, Cambodia and Malaysia. India, Malaysia and USA are three strategic country partners of QUB.

Community and rural outreach activities:

(i) Rural training events: 8 in West Bengal, India, 3 in Kota Bharu and Kuala Terengganu (Malaysia) and one in Lummi Island, Washington State, USA. Total number of participants exceeds 2000 people.
(ii) Train the trainers programme for setting up water treatment plants: Calcutta (3), Tata Steel City, India (3), and Phnom Penh (2). Total number exceeds 1000.

In a meeting held in Calcutta on 15 November 2011, between the Vice Chancellor of QUB, the Deputy High Commissioner of UK and the Chief Minister of West Bengal, a large water scheme for 0.7 million people in Nadia District of West Bengal for arsenic removal using QUB's SAR technology was approved. The construction work started immediately. The new community plants run on solar power.

International prizes recognising this impact

(1) Asian Water Industry Excellence Award in Asia Water 2010, Kuala Lumpur, 2010
(2) St Andrews Prize for the Environment, St Andrews University/ConocoPhillips, 2010 (***grant 7, source 7***)
(3) Energy Globe Award for India - Energy Globe Foundation (Austria), awarded in Dublin, 2012
(4) Green Apple International Award (Green Organisation, UK), London, 2012
(5) Energy Globe World Award in the category 'Water', Vienna, 2012

5. Sources to corroborate the impact (indicative maximum of 10 references)

(1) "Arsenic Removal West Bengal, India", Blacksmith Institute, New York (http://www.worstpolluted.org/projects_reports/display/76)
(2) "Top ten successful solutions against dangerous pollutants 2009", Green Cross Switzerland (http://www.greencross.ch/en/news-info-en/environmental-reports/ten-best-pollution-solutions/2009.html)
(3) "New system removes arsenic from groundwater", Norren Parks, 'Dispatches Section', 'Frontiers in Ecology and Environment', The Journal of the Ecological Society of America, April 2011, p. 145 (http://www.frontiersinecology.org/current_issue/aprilDispatches2011.pdf)
(4) "Pioneering Technology Creates Safer Drinking Water in the United States", Environmental Protection (http://eponline.com/articles/2011/03/02/pioneering-technology-creates-safer-drinking-water-in-the-united-states.aspx)
(5) "Low-Tech Solution Could Reduce Dangerous Arsenic Levels in India, Bangladesh", Voice of America – news and audio (http://www.voanews.com/english/news/a-13-2008-09-18-voa39-66687562.html)
(6) "Arsenic: when will the clean water start flowing?", SciDev Net (http://www.scidev.net/en/features/arsenic-when-will-the-clean-water-start-flowing--1.html)
(7) Comments from VC of St Andrews and President of ConocoPhillips (http://www.thestandrewsprize.com/2010-video.htm)