Accounting for Sustainability in Bengal: Examining Arsenic Mitigation Technologies using Process Analysis Method

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Abstract

This thesis shows how the Process Analysis Method (PAM) can be applied to assess technologies used to mitigate arsenic from drinking water in rural India, using a set of sustainability indicators. Stakeholder perspectives, gathered from a fieldwork survey of 933 households in West Bengal in 2012, played a significant role in this assessment. This research found that the 'Most Important' issues as specified by the technology users are cost, trust, distance from their home to the clean water source (an indicator of convenience), and understanding the health effects of arsenic. It was also found that none of the ten technologies evaluated are economically viable, as many do not charge user-fees, which creates reliance upon donations to meet recurring costs. Utilisation of a technology is strongly related to sociocultural capital, but in many cases, features that contribute to sociocultural value, like regular testing of the treated water, are not included in the financial budget. It is suggested that increased awareness might change attitudes to arsenic-rich waste and its disposal protocols. This waste is often currently discarded in an uncontrolled manner in the local environment, giving rise to the possibility of point-source recontamination. All technologies proved to have difficulties in dealing with waste, except the Tipot and Dug wells which produce no waste. Of the methods considered, the BESU technology scored highest, but still only with 47-62% of the maximum scores achievable within each domain. This explains the widespread failure of mitigation projects across the region. The indicators and metrics show where improvements can be made. A model scheme based on these findings is outlined which could be applied with the objective of increasing utilisation and improving sustainability. It can be concluded that a product stewardship approach should be taken in regard to design, implementation and operation of the technologies, including the creation of a regulated toxic waste collection and disposal industry.

Why do you use the filter? Why did you stop?*

"The operator built a new house. Where did he get the money? It's wrong for him to profit when water should be free. I refuse to pay."

"The community club is in charge of that water. I trust them so I use the filter."

"I have never seen the operator clean it. He has no boss. So I don't use it."

"The filter looks dirty and old."

"I don't know who installed it. It's broken. It has been broken for years. There is no number to call for help."

"The flow is too slow; I don't have time to wait."

"I get loose movements after I drink that water so I don't use the filter anymore."

"It costs too much."

"The operator washes his cow in that water. So it must not be drinkable."

"Dr. Chakraborti from Jadavpur University in Kolkata told me to use this filter, so I do."

"The filter broke."

"Would you drink water from that? It looks like a heap of garbage. I don't trust it."

"The Panchayat [village leader] doesn't use the filter, so it must not work."

"The ball inside costs too much to replace, so after it expired I stopped using the filter."

"Now the operator wants money from us. I thought the NGO was paying him? Maybe he is corrupt."

*All of the quotes are translations from Bengla. All of the people photographed gave verbal consent.

Meet the people…*

Hand-rolling cigarettes made from leaves for supplementary family income.

This woman welcomed me into her home for tea during a monsoon downpour.

Married women typically wear red saris.

Sewing nets and hamocks to sell at the market.

Except her favorite colour is purple.

White saris are worn by widows.

I dedicate this piece of work to:

My Opa (Walter Hoffmann), who understands my soul;

My Mom (Ute Etmannski) who doesn’t, but who is unrelentingly loving regardless;

My big brother (Jonathan Etmannski), for being my best friend.

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who, despite some misunderstandings, I know love me deeply

and are proud of this achievement.

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List of Abbreviations

Activated Alumina	AA
All Indian Institute of Hygiene & Public Health	AIIH&PH
Arsenic Removal Plants	ARP
Arsenic-Rich Waste	AsRW
Trivalent Arsenic	As(III)
Pentavalant Arsenic	As(V)
Below Detection Limit	BDL
Bangladesh Environmental Technology Verification – Support to Arsenic Mitigation	BETV-SAM
Bengal Engineering and Science University	BESU
British Geological Survey	BGS
Central Glass & Ceramic Research Institute	CGCRI
Composite Iron Matrix	CIM
Department of Public Health Engineering	DPHE
Driving Forces, Pressures, States, Impacts, Responses	DPSIR
Defence Research and Development Organisation	DRDO
Energy Alternatives India	EAI
Extended Producer Responsibility	EPR
Iron Oxyhydroxide	FeOOH
Ganges, Brahmaputra and Meghna river system	GBM
Global Reporting Initiative	GRI
Hydrochloric Acid	HCl
Household Deep Tube Well	HDTW
Hydrous Ferric Oxide	HFO
Household Shallow Tube Well	HSTW
Industrial Ecology	IE
International Institute of Bengal Basin	IIBB
Indian Institute of Technology – Bombay	IITB
Indian Power Sector	IPS
Mott MacDonald Ltd.	MML
Municipal Solid Waste	MSW
Nanofiltration	NF

Non-Governmental Organisation	NGO
Pal Trockner Envitech Ltd. / Harbauer India Ltd.	PalT/Harbr
Process Analysis Method	PAM
Public Deep Tube Well	PDTW
Public Health Engineering Directorate	PHED
Product Stewardship	PS
Product Stewardship Institute	PSI
Public Shallow Tube Well	PSTW
Polyvinyl Chloride	PVC
Survey Question	Q
Indian Rupees	R
Ramakrishna Vivekananda Mission – Institute of Advance Studies	RKVM-IAS
Reverse Osmosis	RO
Rural Sanitary Mart	RSM
Solar Oxidation and Removal of Arsenic	SORAS
Toxicity Characteristics Leaching Procedure	TCLP
Technology for In-situ Treatment for Potable Groundwater	TIPOT
United Nations Development Programme	UNDP
United Nations Fund for Population Activities	UNFPA
United Nations International Children’s Emergency Fund	UNICEF
United States Environmental Protection Agency	USEPA
World Bank Development Indicators Database	WBDID
World Health Organisation	WHO
Wagtech’s Visual Colour Detection Kit	WVCD Kit
Zero Valent Iron	ZVI

1 Introduction, Context and Background

1.1 Introduction

The presence of arsenic in groundwater was recognised as a widespread and significant challenge to public health in the 1990s and it is now known to be a problem in over 70 countries (Ravenscroft et al., 2009). Consumption of arsenic-contaminated water leads to a variety of fatal illnesses and is a hazard that primarily affects rural residents due to their lack of access to municipal scale, potable water resources (Smith et al., 2000). Many different technologies are available to remove arsenic from local water supplies, but their particular application may not always be appropriate for local sociocultural, economic or environmental reasons, particularly in developing nations. In West Bengal, India, a significantly high percentage of arsenic removal technologies fail within their first year of use which results in the population remaining at risk. To prevent this from happening, it is crucial that reasons for failure are recognised, and that only the most appropriate and sustainable technologies are implemented. The purpose of this research is to create a transparent sustainability assessment of the ten most widely used arsenic mitigation options in West Bengal, India. Having a comprehensive and proven method of assessment should improve the selection of suitable water treatment options and thus reduce the exposure of this large rural population. The assessment method should also highlight ways in which the technology and implementation can be better designed to suit the needs of the users. The most optimistic outcome of this project is improving the health of Bengali communities. This chapter describes the background and context of the arsenic problem, explains the geoscience related to arsenic and considers various general approaches to drinking water and waste treatment. Finally the aims and objectives of this research programme are given.

1.2 Arsenic Pollution/Contamination

Arsenic is a poisonous metalloid which is virtually colourless, odourless and tasteless when dissolved in water (Meharg 2005). It exists in more than 200 naturally occurring minerals and thus can be found in small quantities in sediments, soil, rock, air, water, plant life and organisms across the globe (Appelo and Postma, 1996). In recent history, arsenic has been utilized in the lumber industry, in herbicides and pesticides, chemicals and electronics and as an additive in agricultural feed. It is often a by-product in mining (gold, copper, coal) and in metal production (lead and copper smelters) (Cullen and Reimer, 1989). As a consequence, many local accounts of arsenic pollution have been related back to these specific industries. Several review papers cover arsenic contamination on a global scale, which together have compiled an impressive number of examples of arsenic pollution dating back as early as 1910 (Mandal and Suzuki, 2002; Smedley and Kinniburgh, 2002; Mukherjee et al., 2006; Cullen, 2008). Mandal and Suzuki (2002) include several historical examples of contamination in the food industry, where arsenic was found in powdered milk in Japan, beer in England and wine in Germany due to the use of arsenic in pesticides. Some high concentrations of arsenic were initially attributed to anthropogenic influence, but were later found to be naturally occurring (Chatterjee et al., 1993; Mazumder et al., 1998).

In the past, arsenic levels in groundwater were not routinely tested for (Clarke, 2001). However, in the last three decades, there has been a re-examination of the factors which control how arsenic is distributed throughout the environment, resulting in more arsenic testing and a significant growth of knowledge of the properties and behaviours of arsenic (Smedley and Kinniburgh, 2002). It has been only since 1990 that naturally-occurring arsenic contamination in groundwater has been recognised as a global problem (Ravenscroft et al., 2009). Twelve countries with newly discovered contamination are in Asia, those being Afghanistan, Bangladesh, Cambodia, China, India, Lao PDR, Mongolia, Myanmar, Nepal, Pakistan, Thailand and Vietnam. The most severely affected region of the world is in the Bengal basin. The number of people at risk from arsenic contamination in this region is not known with certainty but a conservative estimate might be 40 million (Smedley and Kinniburgh, 2005), and as many as 200 million have been mentioned (Chakraborti et al., 2002). The estimates depend on the predicted population density, models of hydrogeology and thus predicted distribution of arsenic, and what concentration of arsenic is used to define the level of contamination which constitutes a risk.

1.3 Bengal Basin Background

1.3.1 Terminology

The Bengal basin is a geological term which includes the delta of the Ganges, Brahmaputra and Meghna (GBM) rivers at the Bay of Bengal, situated along the border between Bangladesh (formally known as East Bengal) and the province of West Bengal, India (Mukherjee et al., 2009). Though arsenic contamination crosses national borders, since both sides are geologically, geochemically and culturally very similar, this thesis will use the term the Bengal basin or simply Bengal for the geographical region where the arsenic problem is encountered at this locale.

1.3.2 Tube wells

The exposure of the population to arsenic in the Bengal basin began 40 years ago when there was a rapid increase in the installation of tube wells, which gave people access to fresh, cool, bacteria-free groundwater. A tube well is a water well, constructed using low-level technologies of hand-auguring to ‘sink’ it. The tube is usually a polyvinyl chloride pipe, 25-200mm in diameter targeting either ‘shallow’ groundwater (<100-

150m) or ‘deeper’ aquifers (>150m) . It is connected to a cast-iron or steel hand pump at the surface (Bukhari et al., 1980). In the Bengal basin, the sediments are fairly soft and the groundwater table is often only approximately 15m below ground level, so tube wells can be installed relatively easily and at little cost (Mukherjee et al., 2009).

Different reasons have been given for the rapid introduction of tube wells. Some claim that the West Bengal Government initiated an incentive programme (in 1965) for farmers to irrigate new strains of rice during the Green Revolution (Ahmad, 1972; Department of Information and Cultural Affairs, 1986; Beck, 1995; Harvey et al., 2005; Mukherjee et al., 2007; Cullen, 2008). Other authors claim that in the mid-1970s the government was promoting the installation of tube wells because they provided drinking-water free from the pathogens commonly found in rivers and ponds, which was causing diarrheal disease across the region (Ebi et al., 2005; Ravenscroft et al., 2009). Focusing on eliminating bacteria-caused waterborne diseases, in 1970 the United Nations Children’s Fund (UNICEF) began a programme to help provide safe drinking water throughout the region by repairing broken tube wells and installing new ones (UNICEF, 2000). Today approximately 97% of the rural population relies on tube wells as their source of drinking water and it is estimated that over 11 million shallow tubes wells exist in Bengal (World Bank, 1998; British Geological Survey, 1999). This large number of wells, 75% of which are privately owned, now poses serious analytical challenges with regard to accurate and practical water-testing methods (Kinniburgh and Kosmus, 2002), required to certify water quality. The number of tube wells being installed is still increasing today (Chakraborti et al., 2009). A very recent comparison of two blanket surveys conducted 12 years apart within only a 25km^2 area in Bangladesh indicates the total number of tube wells within that area doubled from 5560 to 10,879 wells (Van Geen et al., 2014). Bengal is approximately 230,000km^2 in area, and is one of the most densely populated regions on Earth. It has an estimated population of more than 250 million people and a population density that exceeds 900/km² (WBDID, 2006).

1.3.3 Diagnosis of Arsenicosis

Dr KC Saha, a dermatologist at the School of Tropical Medicine in Calcutta (Kolkata), diagnosed the first case of chronic arsenical dermatosis in July 1983 (Saha, 1984). After investigating several rural areas in the vicinity, he identified 1214 additional cases of arsenicosis (chronic arsenic poisoning or toxicity). He tested water from the tube wells and determined the arsenic source to be groundwater (Saha, 2003). DNG Mazumder and AK Chakraborty led a team of doctors to further investigate and found tube wells with water containing as much as 2000ppb of arsenic, which is 40 times the local drinking water limit (Gov't of India) of 50ppb (WHO recommends a maximum concentration of 10ppb). Most natural waters contain less than 1ppb of arsenic (WHO, 2001). The researchers reported their findings in a WHO Bulletin in 1988 (Mazumder et al., 1988).

The adverse health effects of arsenic have since been studied extensively and it has been determined that the degree of arsenicosis depends on the dose, duration of exposure and the current health of the population exposed (Mazumder et al., 1998). A recent study (Sarkar, 2010) determined that poverty was one of the major determinants of arsenic exposure level, showing links between degree of exposure and a subject's occupation, nutritional status (gender) and access to health care. Physical disability and disfigurement which are symptoms of arsenicosis have made the poor more vulnerable to economic and social exclusion, so that arsenicosis contributes to worsening social disparity in the Bengal region (Sarkar, 2010).

1.3.4 Symptoms and Treatment

There are many symptoms of arsenicosis, but the most common are skin lesions in the form of melanosis and keratosis (Rahman et al., 2009). A number of articles have been published on chronic exposure to arsenic and its health effects (Naqvi et al., 1994; Rahman et al., 2001; Mandal and Suzuki, 2002; Ng et al., 2003; Duker et al., 2005; Ebi et al., 2005; Rahman et al., 2005; Wang et al., 2007; Cherry et al., 2008; Vahter, 2009). Drinking arsenic-contaminated water may lead to skin cancers, cancer of the bladder, kidneys, lungs, and diseases of the blood vessels of the legs and feet. It may also contribute to diabetes, high blood pressure and reproductive disorders. Arsenic in drinking water is absorbed by the intestines from where the bloodstream takes it to various organs. It contributes to adverse health effects by inhibition of essential metabolic enzymes, preventing DNA from mending which ultimately leads to death from multi-system organ failure (Paul and Tinnon Brock, 2006). Approximately 1 in 100 people whose primary source of drinking water contains 50ppb or more will eventually die from arsenic related cancers (WHO, 2001).

Despite its toxicity, there are few studies on effective therapy or treatment of arsenic poisoning. Although experimental studies indicate an effect of chelation therapy in reducing the arsenic stores in the body, no clinical studies have supported the data (Stenehjem et al., 2007). Arsenicosis is then a disease for which no effective therapy is yet known (Das and Sengupta, 2008). There is indication that after switching to arsenic-safe water combined with taking anti-oxidants and eating high amounts of protein, arsenicosis symptoms may be reversed when the disease is in its early stages (Howard, 2003).

1.4 Chemistry

Arsenic has multiple oxidation states (+5, +3, 0 and -3). Trivalent arsenic – As(III) and pentavalent arsenic – As(V) are the most common inorganic forms in natural environments. Speciation of arsenic is important for both toxicological studies and remediation efforts as the mechanism for the removal of arsenic from contaminated water is highly species dependent. As(III) is 60 times more toxic than As(V) and inorganic arsenic is 100 times more toxic than organic compounds (Jain and Ali, 2000). The speciation and solubility of inorganic arsenic is sensitive to both redox conditions and pH of the environment which affects both the toxicity and mobility of arsenic. In an anoxic system, the stable form of arsenic is As(III) which has higher toxicity and mobility than As(V). In aquifers, arsenic frequently adsorbs to iron oxyhydroxide - FeOOH, and so the behaviour of FeOOH is also an important factor in regulating arsenic movement and concentration. For example, under aerobic (oxidizing) conditions, As(V) dominates and FeOOH is insoluble, so this compound acts as a sink for arsenic (removes arsenic from the water). In contrast, under anaerobic (reducing) conditions, As(III) dominates and FeOOH readily dissolves, which releases arsenic from the rock into the groundwater, thereby acting as an arsenic source. These behaviours are crucial to understanding the chemical and physical mechanisms in the removal of arsenic from groundwater.

1.5 Geoscience

1.5.1 Geomorphology and Stratigraphy – Understanding the Arsenic Source

The Bengal basin is a classic example of a peripheral foreland basin formed by continent-continent collision. It is the result of the subduction of the Indian tectonic plate below the Eurasian (Tibetan) and Burmese plates. The basin is located at the junction of these three plates and is subsiding at a rate of 2-4mm/year (Evans, 1964; Mukherjee et al., 2007). It is also the largest fluvial-deltaic sedimentary system on earth. Arsenic-containing sediments erode from the Himalayan Mountains and are carried down the Ganges, Brahmaputra and Meghna river systems to accumulate in the basin or disperse out into the Bay of Bengal. The sedimentary sequences found in this basin are strongly influenced by the meandering character of these rivers and also by sea level fluctuations during the evolution of the Bengal delta (Umitsu, 1987 and 1993). The primary sources of arsenic within the Himalayas are thought to be eroding coal seams and rocks containing sulphide minerals (Acharyya et al., 2000). During transport, arsenic appears to have adsorbed onto FeOOH-coated sand grains and clay minerals (Acharyya et al. 2000) which were then deposited across the delta, creating large sequences of (arsenic-coated) channel sands, the ideal depositional environment in which aquifers later form.

1.5.2 Aquifers and Hydrogeology – Understanding regional heterogeneity

There are two major physiographical units in this region; Pleistocene (deeper) and Holocene (shallower) sediments. The extensive occurrences of these alluvial sediments combined with abundant sources of recharge from rainfall and floodwater during the monsoon season have resulted in the development of prolific aquifer systems across the Bengal delta (Bhattacharya et al. 2009). The vast majority of the tube wells providing water for human consumption are drilled into the shallow Holocene aquifers, as some are less than 5m from surface. Far fewer wells are drilled into the deep (>200m) Pleistocene aquifers (Bhattacharya et al., 1997).

The British Geological Survey, Department of Public Health Engineering (Government of Bangladesh) and Mott MacDonald Ltd (UK) carried out an extensive hydrogeological study of Bangladesh in 2001 (BGS/DPHE/MML, 2001). Mukherjee et al. published the first interpretation of the regional-scale hydrostratigraphy and groundwater flow model for the West Bengal side of the Bengal basin in 2007. When the results from the two studies are viewed together, they show that regionally there are discontinuous clay layers (aquitards) that locally divide near-surface aquifers. These layers have low hydraulic conductivity so that marked variations in hydraulic head and water quality are observed (Bhattacharya et al., 2009). There are also seasonal variations of flow on a regional scale. These studies also suggest that extensive pumping has severely distorted the subsurface flow patterns inducing high vertical gradients across wide cones of depression. The complex stratigraphy as well as local and regional groundwater flow explains how tube wells can have very different groundwater quality even when located close to each other.

1.5.3 Geochemistry – Understanding arsenic release from sediments

Destabilizing arsenic from the iron oxide complexes is now recognized as a key step in the widespread contamination of groundwater (Fendorf et al., 2010). It has been determined that arsenic in this region is liberated under reducing conditions mediated further by microbial action (Nickson et al., 1998; Nickson et al., 2000). McArthur et al. (2004) propose that organic carbon already present in the sediments is a driver of microbial reduction. However it has also been suggested that there is intensification of arsenic in groundwater over time with increased human use of the aquifer. When large volumes of water are extracted from shallow aquifers (5-40m deep), this draws down surface water that is rich in organic compounds. These then fuel the microbes that aid in the reduction of arsenic-bearing iron minerals and arsenic itself resulting in increased concentrations of soluble arsenic in groundwater (Harvey et al., 2002; Polya and Charlet, 2009). It is then clear that understanding the critical factors controlling the biogeochemical cycling of arsenic and iron oxyhydroxides is one important factor in the development of effective strategies to manage arsenic-rich groundwater in the Bengal basin.

1.6 Physiochemical Mechanisms used for Arsenic Removal

In order to remove the arsenic to make the groundwater safe to drink, several physiochemical techniques have been employed including oxidation/reduction, co-precipitation/coagulation (often followed by sedimentation and filtration), sorption and ion exchange (often employing activated alumina), and physical exclusion using membranes (molecular filtration). There is often a need to control pH and/or other parameters to achieve optimum removal. Note that the process of boiling does not remove arsenic from water.[1]

1.6.1 Oxidation

Most treatment methods are effective in removing As(V), but As(III) is more commonly found in groundwater, so oxidation is required as a first step to convert As(III) to As(V) (Chang et al., 2009; Garelick et al., 2005). As(III) can be oxidized by atmospheric oxygen, ozone, chlorine, permanganate and hydrogen peroxide but atmospheric oxygen, hypochloride and permanganate are most commonly used in Bengal (equations 1-3).

$$H_3AsO_3 + \tfrac{1}{2}O_2 = HAsO_4^{2-} + 2H^+ \tag{1}$$

$$H_3AsO_3 + HClO = HAsO_4^{2-} + Cl^- + 3H^+ \tag{2}$$

$$3H_3AsO_3 + 2KMnO_4 = 3HAsO_4^{2-} + 2MnO_2^{+} + 2K^+ + 4H^+ + H_2O \tag{3}$$

Using the method of ‘passive oxidation’ many rural people drink water stored in pitchers because it is thought that the exposure to atmosphere that occurs during

[1] The belief that boiling the water will remove or ‘deactivate’ arsenic was widely encountered during field work in Bengal.

collection and open-air storage may cause a decrease in arsenic concentration. However Ahmed et al. (2001) showed that using this method, there is zero to 25% reduction of the initial concentration and the process is highly dependent on alkalinity and iron content. This method cannot be relied upon to remove arsenic to the required level of 50ppb.

Passive oxidation of arsenic is very slow and can take weeks but chemicals like chlorine and permanganate can rapidly oxidize As(III) to As(V) under a wider range of conditions. Several chemical packages are available in the form of sachets ("tea bags"), powder and tablets that can be used as a 'chemical induced' form of oxidation (Meng et al., 2001). However quality assurance and dose control in rural conditions are extremely difficult, so this oxidation method is not widely promoted.

SORAS is a simple method using 'solar oxidation', which works by placing drinking water in translucent bottles and letting them sit in the sun (Wegelin et al., 2000). Ultraviolet radiation catalyses the process of oxidation of As(III), and this can be followed by precipitation and filtration of As(V) adsorbed on Fe(III)oxides (Wegelin et al., 2000). This process is also highly dependent on alkalinity and iron content of the untreated water. Field tests show a removal efficiency average of 67% (to lower the arsenic concentration to 50ppb) (Young, 1996), which limits the use of this technology to raw water having an initial arsenic concentration no higher than 100-150ppb. This method of removal is very uncertain since testing in rural areas is rarely possible.

1.6.2 Co-precipitation / Coagulation

Water treatment with coagulants such as aluminium sulphate - $Al_2(SO_4)_3.18H_2O$, ferric chloride - $FeCl_3$, and ferric sulphate - $Fe_2(SO_4)_3.7H_2O$ are also effective in removing arsenic from water. The ferric salts have been found to be more effective in removing arsenic than aluminium over a wider range of pH (Ahmed, 2001). In the coagulation-flocculation process, aluminium sulphate, ferric chloride, or ferric sulphate is dissolved in the water and stirred for a few minutes. Micro-flocs form rapidly, and as stirring is continued, agglomeration of micro-flocs into larger particles occurs. During this flocculation process many different kinds of micro particles and negatively charged ions are attached to the flocs by electrostatic attachment. Since As(III) occurs in non-ionized form, it is not subject to significant removal, so that oxidation of As(III) to As(V) is an essential pre-treatment (equations 1-3). A typical chemical scheme (for aluminium coagulation) is as follows:

Aluminium dissolution: $Al_2(SO_4)_3.18H_2O = 2Al^{3+} + 3SO_4^{2+} + 18H_2O$ (4)

Aluminium precipitation (acidic): $2Al^{3+} + 6H_2O = 2Al(OH)_3 + 6H^+$ (5)

Co-precipitation (Non-stoichiometric, non-defined product):

$H_2AsO_4^- + Al(OH)_3$ = Al-As (complex) + Other Products (6)

Arsenic adsorbed on aluminium hydroxide flocculants as Al-As complex is then removed by sedimentation and filtration. The possible reactions of arsenate with hydrous iron oxide are shown below where [$\equiv FeOH^o$] represents oxide surface sites (Dixit and Hering, 2003).

$Fe(OH)_3(s) + H_3AsO_4 \rightarrow FeAsO_4.2H_2O + H_2O$ (7)

$\equiv FeOH^o + AsO_4^{3-} + 3H^+ \rightarrow \equiv FeH_2AsO_4 + H_2O$ (8)

$\equiv FeOH^o + AsO_4^{3-} + 2H^+ \rightarrow \equiv FeHAsO_4^- + H_2O$ (9)

Efficient arsenic removal is dependent on pH. In aluminium coagulation, the removal is most effective in the pH range 7.2-7.5. In iron coagulation, efficient removal is achieved in a wider pH range usually between 6.0 and 8.5 (Ahmed and Rahaman, 2000).

1.6.3 Sorption

Sorption describes the complexing of an ion to a surface without the need for other ions to be removed. In this process, sorption can alter the surface charge. Numerous studies have quantified and modelled As(V) and As(III) sorption onto amorphous iron oxides, goethite, and hematite (Appelo et al., 2002; Bowell, 1994; Goldberg and Johnston, 2001; Manning et al., 1998). Competition between arsenic and other sorbates (such as phosphate, silicic acid, and bicarbonate) has also been studied (Swedlund and Webster, 1999). Phosphate, whose concentrations in groundwater can exceed those of arsenic, is particularly effective at competing with arsenate for sorption sites on iron oxide minerals (Gao and Mucci, 2001). Several sorptive media have been reported to remove arsenic from water. These are activated alumina, activated carbon, iron and manganese coated sand, kaolinite clay, hydrated ferric oxide, activated bauxite, titanium oxide, silicium oxide, and a variety of biosorbent materials, such as coconut husks and water hyacinth leaves. Mohan and Pittman (2007) summarized the arsenic adsorption capacities for over 100 adsorbents.

1.6.4 Activated Alumina

Activated alumina, Al_2O_3 has a good sorptive surface which is an effective medium for arsenic removal. When water passes through a packed column of activated alumina, the arsenic present is adsorbed on the surfaces of activated alumina grains. Regeneration of saturated alumina is carried out by exposing the medium to 4% caustic soda, NaOH, either in batch or by flow through the column resulting in highly arsenic-contaminated caustic waste water. The residual caustic soda is then washed out and the medium is neutralized with a 2% solution of sulphuric acid rinse. During the process about 5-10% alumina is lost and the capacity of the regenerated medium is reduced by 30-40%. The activated alumina needs replacement after 3-4 regenerations (Sarkar et al., 2005 and 2008).

1.6.5 Ion Exchange

Ion exchange itself is an adsorption reaction. In ion exchange, an ion sorbs to the surface by removing another ion of the same valence or multiple ions of lower valence. In this way, ion exchange never changes the surface charge. The process is similar to that using activated alumina, but the medium is a synthetic resin of well-defined ion exchange capacity. The process is normally used for removal of specific undesirable cations or anions from water. As the resin becomes exhausted, it needs to be regenerated. The arsenic exchange and regeneration equations with common salt solution as regeneration agent are as follows:

Arsenic exchange: $$2R\text{-}Cl + HAsO_4^{2-} = R_2HAsO_4 + 2Cl^- \quad (10)$$

Regeneration: $$R_2HAsO_4 + 2Na^+ + 2Cl^- = 2R\text{-}Cl + HAsO_4^{2-} + 2Na^+ \quad (11)$$

Where R stands for ion exchange resin.

The arsenic removal capacity is dependent on sulphate and nitrate contents of raw water as sulphate and nitrate are exchanged before arsenic. The ion exchange process is less dependent on pH of water than is the process of sorption (Section 1.6.5).

1.6.6 Membranes

Membranes are selectively permeable so that some molecules can pass through them while others are rejected. Membrane processes have the ability to remove bacteria, salts and metals including arsenic. There are low-pressure membranes like microfiltration and ultrafiltration and high pressure membranes such as nanofiltration (NF) and reverse osmosis (RO). It was shown by Sato et al. (2002) that a nanofiltration membrane removes over 95% of As(V) and 75% of As(III) without the addition of any chemicals and thus could be used in any type of water. The more recent generation of NF and RO technologies that have been developed can operate at lower pressures (40-400psi) and were able to reject 96-99% of both As(V) and As(III) (Ravenscroft et al., 2009). However membrane filtration requires relatively high quality influent water as the membranes can be fouled by colloidal matter (organic) which makes this technology less useful in a rural field setting. The membrane itself does not collect arsenic so membrane disposal is simple and operation and maintenance is minimal. Maintenance includes ensuring that there is a reasonably constant pressure and periodically wiping the membrane clean. However a major disadvantage is the low recovery rate of only approximately 10-20% of raw water passing through the membrane. Further, membrane units have a high capital cost which makes this technology less suitable for rural and poor communities. So, though membrane technologies have been shown to be effective in removal of arsenic, they are not economically feasible for rural people of the Bengal basin (Bissen and Frimmel, 2003; Elcik et al., 2013).

1.7 Arsenic-Rich Waste

Given the scale of the arsenic problem and the increased application of arsenic removal technologies, it can be expected that large quantities of arsenic-rich waste is generated. The disposal of arsenic-rich waste is a major concern because of the potential for arsenic release at waste disposal sites and subsequent recontamination of water sources. Arsenic-bearing solid wastes from drinking water treatment in developed countries are typically disposed of in municipal solid waste landfills (Cornwall, 2004). Since there are virtually no engineered landfills in rural India, different disposal options must be considered. Clancy et al. (2013) critically reviewed the different disposal methods of arsenic-rich waste produced by the removal processes outlined in section 1.6. They concluded that the disposal strategies with the most potential in developing countries are the use of passive aeration and concrete stabilization, but also pointed out that more research is required to better understand how these methods perform in the long term when exposed to field conditions.

1.7.1 Passive Aeration

In some regions in the Bengal basin, spent iron/aluminium hydroxide adsorbent media from filters is said to be collected and brought to a central location. This spent adsorbent is disposed of by burying it in a controlled manner and keeping it exposed to air by way of vented PVC-piping within a coarse sand filter (Sarkar et al., 2008). This is done to avoid reductive dissolution and the subsequent release of arsenic from oxidized arsenic-bearing wastes by keeping it oxidized (Sarkar et al., 2010). Clancy et al. (2013) suggest that long-term performance of this system, as well as the effects of changing environmental conditions, including redox and pH, caused by flooding and cycles of wetting and drying, still need to be assessed. Though this method has potential, it is not widely used.

1.7.2 Concrete Stabilization

Solidification/stabilization of hazardous waste, whereby the waste is encapsulated and strengthened (solidification), and the toxicity and mobility are reduced (stabilization), is a treatment strategy that is often quoted in the literature as a viable option for the Bengal basin. However it is rarely utilized. This method requires the addition of lime, concrete, and/or iron containing additives (Raj et al., 2005). Following solidification/stabilization, arsenic wastes could be disposed of in landfills or used in the making of bricks (Kameswari and Bhole, 2001). Interactions between waste and concrete can affect arsenic stability and concrete strength so each type of waste needs to be considered uniquely when determining waste disposal options (Sullivan et al., 2010). Laboratory and field studies are needed to evaluate long-term arsenic leaching potential. A risk analysis for humans is also required since the use of arsenic-contaminated bricks could give rise to repeated exposure of workers during the construction stage and of residents, due to erosion of the bricks.

1.7.3 Mixing with Cow Dung

A popular waste disposal method commonly referred to in Bengal is the mixing of arsenic waste with cow dung. This is intended to promote microbial arsenic methylation to produce gaseous methylarsines that are less toxic to mammals than inorganic forms. However limited additional research has been performed to support substantial arsenic removal through volatilization in this disposal scenario, and more recent studies reported that only a small fraction of arsenic was volatilized when cow dung was added to arsenic contaminated soils (Turpeinen, 2002). Additionally, there has been no suggestion on what to do with the cow dung after the mixing. This poses serious potential health risks since dried cow dung is commonly used as a fuel for cooking in Bengal and inhalation of arsenic poses as serious health effects as ingestion (Smith et al., 2009).

1.7.4 Dumping

The most commonly used method for disposal of arsenic-rich waste is dumping, either on the soil or in a dynamic environment like a pond or stream. This type of disposal is not widely studied, nor included in many discussions of waste management however is the most widely used method observed during fieldwork in this study. Dumping may lead to uptake by fish or crops, increasing the potential arsenic exposure for people living in these areas (Khan et al., 2009). Studies of rice grown in areas with high arsenic soil concentrations and irrigated with arsenic contaminated water highlight this threat to public health (Williams et al., 2006). Meharg and Rahman (2003) found that the ingestion of rice is a major source of arsenic exposure in Bangladesh and that the elevated level of arsenic is due to irrigation of the crops with contaminated water. They also determined that soil previously irrigated with arsenic-contaminated water, and soil in locations where dumping of arsenic-rich waste occurred, will be contaminated indefinitely. These findings highlight that dumping arsenic waste poses significant risk of arsenic exposure to the public, present and future.

1.8 Aim and Objectives

The underlying aim of this thesis is to better understand why so many arsenic mitigation options fail in Bengal. The first objective is to use the Process Analysis Method to create a set of indicators for Sociocultural, Environmental and Economic capital, which together form a triple-bottom-line sustainability assessment. The second objective is to gather information directly from stakeholders in Bengal concerning their needs, concerns and experiences; this requires fieldwork. The next objective is to use the data collected during field work to assess each of the ten most widely utilised technologies in West Bengal, to better understand its performance within the cultural context. The final objective is to discuss any issues as they arise from the analysis (user's perspective) and draw conclusions which will help improve product-design, implementation and policy-creation related to arsenic removal schemes.

2 Clean-Water Technologies

Clean-water options available to rural households in West Bengal vary widely across arsenic-affected areas. A village may have access to municipally treated water from a community shared standpipe (‘time-water’); hand-dug wells which utilize very young, near-surface water which is commonly free of arsenic; or a village-shared, deep groundwater well; alternatively, a family may be using a household-scale or a community-scale arsenic-removal filter. Community-scale filters are more commonly used than household-scale models and are often referred to as Arsenic Removal Plants (ARP) in literature (Hossain et al., 2005; Hossain et al., 2006). Designs vary but typically include sections for oxidation, co-precipitation or sorption, flocculation, sedimentation and filtration. Unfortunately there are many models of ARPs that do not work once implemented in a field setting. A major study was done on 577 ARPs in the Bengal basin which showed that 82.3% of them were not functioning at the time of the survey (Hossain et al., 2005; Hossain et al., 2006). UNICEF produced an information pamphlet for an international conference on water quality with special reference to arsenic which was held in Kolkata in February of 2012. This pamphlet listed the most widely used arsenic mitigation technologies in West Bengal (Public Health Engineering Department, 2012), and below are descriptions of ten of those systems which have been evaluated in this research. Of these, seven are community-scale and three are household-scale. For additional details about these technologies, specific to every village visited, see Appendix I.

2.1 Community-Scale Technologies

2.1.1 Technology for in-situ treatment for potable groundwater (Tipot)

Photo 1.1 Tipot in one of the villages visited during field research.

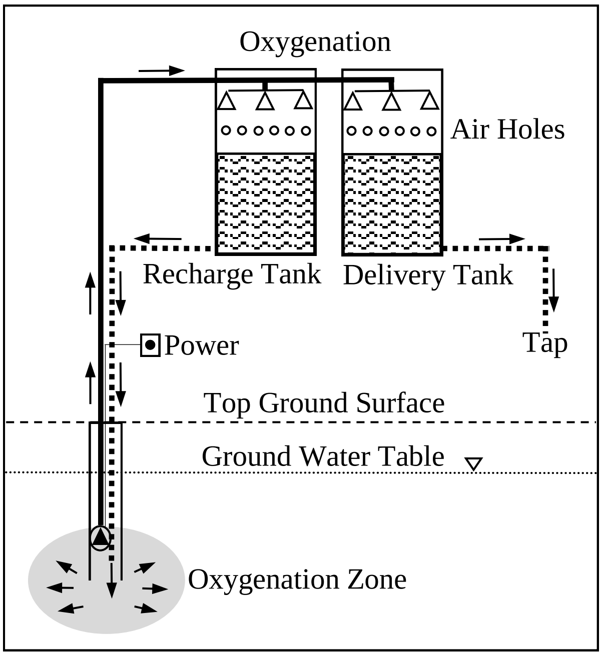

Figure 1.1 Diagram of the Tipot (modified from SAR, 2010).

The Tipot was designed by a consortium of select European universities and Indian research institutes led by Dr Bhaskar Sen Gupta at Queens University Belfast. Under the guidance of Sen Gupta, an NGO called Ramakrishna Vivekananda Mission - Institute of Advanced Studies (RKVM-IAS) from Agarpara, India, won the 'Global Development Marketplace Competition' in 2006, under the 'Water and Sanitation for the Poor' category (Sen Gupta et al., 2009). As a result, the World Bank allotted RKVM-IAS funds to install six plants at six separate locations in rural West Bengal. These funds paid for all the capital costs and recurring costs for five years. By 2012, only two remain operational, and were both visited and included in this study.

The Tipot uses subterranean groundwater treatment which is based on the same principle of oxidation and filtration as used by of conventional surface treatment plants. In this case, the underground aquifer is used as a natural biochemical reactor and adsorber that removes arsenic, iron and magnesium. Water is pumped from the underground aquifer using a submersible pump. The water is aerated and 15–20% of it is returned to the aquifer, while the remainder is supplied as arsenic-free water to the community (Figure 1.1; Photo 1.1). The process of aeration at surface, followed by recharge of the oxygen-rich water to the aquifer, increases the dissolved oxygen concentration in the groundwater (Sen Gupta et al., 2009). The iron that is adsorbed to the surface of the soil grains is oxidized by the oxygen-rich water, into insoluble iron oxyhydroxide which removes arsenic as a co-precipitation product.

The greatest advantage of this process is there is no arsenic-rich waste produced above ground, as the source arsenic and iron are trapped in the underground sand. Sen Gupta claims there is no restriction to the amount of arsenic the aquifer-sands can handle, as long as proper time is allowed for the oxygen-rich water to create the adequate oxidizing zone in the aquifer. However no long-term analysis or modelling has been completed to prove this claim. Other disadvantages include the very long implementation phase, which can range from several months to over a year to complete reclamation of an aquifer before the water is safe enough to drink. There has also been no research published on how irregular activity in usage of the technology may affect the aquifer's water quality. For example, during fieldwork many people expressed concern that the water was too hot to drink in the summer months, as the storage tanks are black and thus absorbs sunlight. So many people are only inclined to use the system during the rainy season, leaving the Tipot largely unused for several months. The consequences of periods of non-use on the oxidation phase in the aquifer are unclear.

Treated water is provided free to all villagers. The operator was appointed and trained by RKVM-IAS but is not paid. Now that the grant awarded to this project has expired (after five years), the operator has been left to pay the electricity bill and other recurring costs himself.

2.1.2 Indian Institute of Technology, Bombay (IITB)

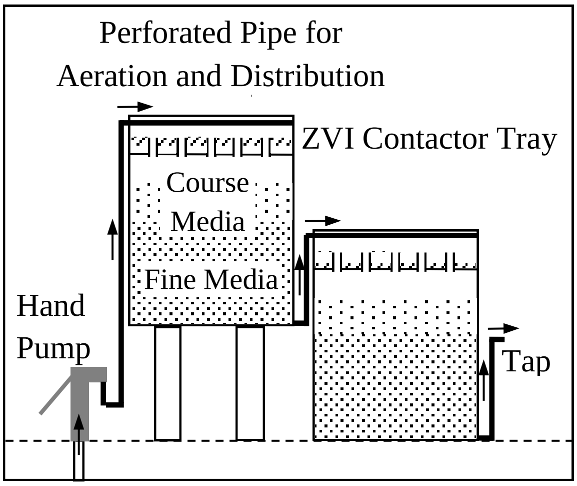

Figure 1.2 Diagram of IITB

Photo 1.2 IITB with two tanks

Photo 1.3 Arration of raw water before the adsorption occurs on the iron nails

Photo 1.4 Close-up of the ZVI (iron nails)

The IITB model was conceptualised using the results from Berg et al. (2006) and Roberts et al. (2004) who proved that slow sand filters are robust and effective, and that multiple additions of Fe(II) into a system lead to improved removal of arsenic by sorption to Hydrous Ferric Oxide (HFO). The system was designed and built under a grant from the Department of Science and Technology, Government of India, by Tuhin Banerji, a doctoral student under the supervision of Professor Sanjeev Chaudhari from IIT Bombay. IITB systems have been installed in five villages, all of which were visited, and three were evaluated for this project.

The filter consists of two or three tanks which are similar in design (Figure 1.2; Photo 1.2). With a direct inlet from the hand pump, water is pumped into the top of the first tank and sprinkled into the top trays by way of a perforated pipe (Photo 1.3). The aerated water oxidizes the As(III) to As(V) and then comes into contact with zero valent iron (ZVI) in the form of iron nails which are held in the top trays (Photo 1.4). ZVI is used to leach Fe(II) which oxidises to Fe(III) in the presence of dissolved oxygen. Research has shown that the corrosion of ZVI forms Hydrous Ferric Oxide (HFO) which acts as an adsorbent for arsenic (Kanel et al., 2005). Sand is not used in this filter as it would trap all the HFO in the top layers, and cause clogging which would then require frequent cleaning. Instead, the filter bed is made up of stone chips and gravel which reduces the head-loss and allows the HFO to penetrate deeper into the filter. Deeper penetration of the adsorbent increases the contact time of raw water with the adsorbent, thereby increasing arsenic adsorption capability. A sequence of two or three identical tanks forms a complete arsenic removal system, with a tap at the bottom of the last tank used directly by the consumer. The number of tanks depends on the initial concentration of arsenic in the local aquifer. It was determined that an Fe/As ratio of 10 is needed in field conditions to lower concentrations of arsenic to below 10ppb (Personal correspondence with Tuhin Banerji).

The waste that is generated is a complex of HFO and As(V), which is considered to be relatively stable in oxidized solid form. The IITB team believe that as long as the sludge is exposed to the atmosphere, the bound arsenic will not leach out. They recommend that the sludge be placed into an open-air containment tank which can accumulate dry sludge for up to ten years. When the sludge tank is full, the dried sludge can be used in the construction industry or disposed of in a controlled manner. A sludge tank is kept beside each filter and has a pipe at the bottom to release any excess water. One disadvantage of this waste disposal method is that some arsenic may flow out of the discharge tube with the water and be released back into the environment to contaminate another locale. Additionally, it may be unclear to the villagers what to do with the waste once the sludge tank is full in ten years, or they may not have the ability (financially or physically) to transport it to a safe-disposal facility.

The operator of this system is a volunteer who is responsible for maintenance and repairs. Water is provided free to all villagers.

2.1.3 Bengal Engineering and Science University (BESU)

Photo 1.5 BESU

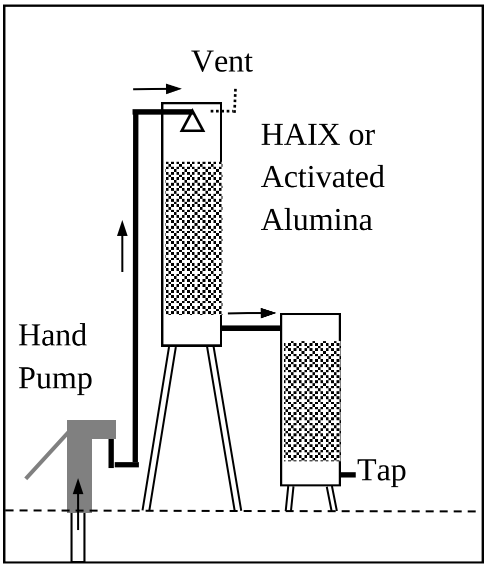

Figure 1.3 Diagram of BESU
(Modified from Sarkar et al., 2010)

In 1997, the Bengal Engineering and Science University in association with Lehigh University, USA, developed a community-scale ARP that they refer to as 'AMAL' but in this research will be called BESU. Alongside various partnering NGOs, they have installed approximately 175 systems across India (Sarkar et al., 2005; Sarkar et al., 2008). Six of these systems were observed in operation, of which three were chosen to be evaluated in this study.

In the top portion of the column, the dissolved iron present in ground water is oxidized by atmospheric oxygen and the water then flows through 50L of activated alumina specific to arsenic binding and/or an arsenic-selective hybrid anion exchanger (HAIX®) (German et al., 2013) The partially treated water then enters the second column containing another 50L of activated alumina or HAIX®, which acts as a polishing unit. Treated water is collected at the bottom of the second column. Both columns have provisions for backwashing. However, the second column rarely requires backwash because most oxidation of dissolved iron and subsequent precipitation occurs in the first column. The general configuration of the sorption column and its operational features are shown in Figure 1.3 and Photo 1.5. The activated alumina is bought from an indigenous manufacturer (Oxide India Limited, Durgapur, West Bengal), whereas HAIX® was developed at Lehigh University and is thus imported. The column is meant to be backwashed for 10–15 minutes every day to drive off the accumulated HFO particulates preventing clogging (Sarkar et al., 2010). The backwashing is done in up-flow mode with the raw water entering from the bottom of the unit. The backwash is dumped into a brick-lined hole adjacent to the filter or into the local environment.

Once per year, the adsorbent requires regeneration. This is done using a caustic soda solution followed by an acid wash. Spent alkali, spent acid and spent rinse water are mixed after each regeneration phase, and the pH is adjusted to around 6.5 by adding hydrochloric acid. Regeneration of 100L of activated alumina produces 1600L of waste solution. Approximately 5L of thick brown precipitate forms rapidly following the pH adjustment and this arsenic laden sludge quickly settles to the bottom of the tank. The contents of the tank are then dumped into a hole in the ground which is filled with stone chips and course filter material. The arsenic-rich sludge sits at the top of the hole as it is the last thing to be poured in, allowing it to dry and to be as exposed to the atmosphere. Similar to the IITB method, it is thought that as long as the sludge is exposed to the atmosphere, the bound arsenic will not leach out. One central regeneration centre is said to be in operation, which services the entire region. However it was not possible to visit this centre in person to confirm the practice of regeneration and waste disposal, despite several attempts.

A village water committee manages the system. The regular maintenance of the unit is administered by an operator who is appointed by the water committee. The users of the filter pay a tariff which is meant to cover all expenditures related to maintenance of the unit, and annual costs of regeneration.

2.1.4 Pal Trockner Envitech Ltd. (PalT) / Harbauer India Ltd. (Harbr)


Photo 1.6 PalT/Harbr with an extra sand filter column used for backwashing

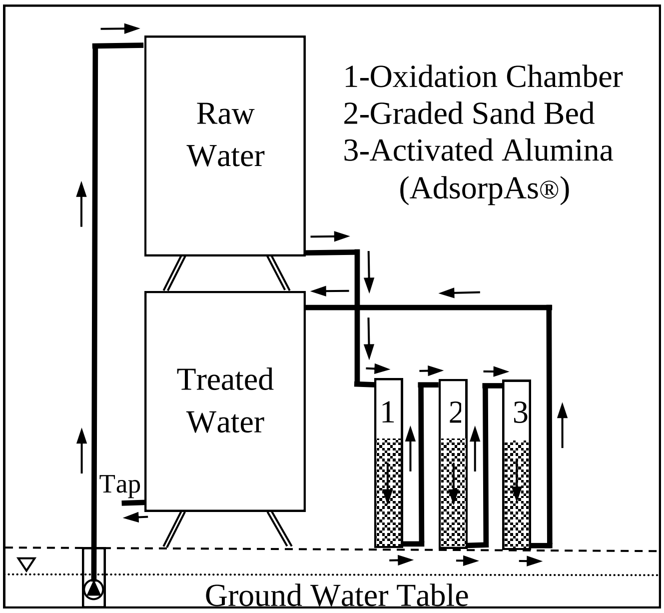

Figure 1.4 Diagram of PalT/Harbr

Pal Trockner was originally partnered with Harbaurer, a German company engaged in the manufacture of water and wastewater treatment plants. They worked together to establish a dominant place in the arsenic-removal industry in India, as the West Bengal government awarded them a contract to install 600 systems across the province.

However, the partnership ended in 2001 and they now operate independently of each other. They do however use exactly the same technology. Two filters from each company were viewed and assessed. In this research, the system both companies use is referred to as PalT/Harbr.

The filter is designed to remove suspended solids, iron and arsenic. The raw water from the tube well is first fed to an oxidation chamber filled with manganese dioxide (MnO_2), which is an oxidising agent (Harbauer, 2012). Water from the oxidation chamber along with the precipitate of ferric hydroxide which was formed in the oxidation process, then passes through graded sand and gravels. The precipitate settles in the sand bed and the now iron-free water flows into an adsorption tower filled with granular ferric hydroxide (otherwise known as AdsorpAs®) which removes arsenic to permissible levels (Figure 1.4; Photo 1.6).

PalT/Harbr claim that the granular ferric hydroxide (AdsorpAs®) is entirely resistant to leaching and thus can be dumped anywhere safely. Toxicity Characteristics Leaching Procedure (TCLP) tests have established that no leaching of arsenic takes place under normal environmental conditions (Pal, 2001). The TCLP defines 'normal environmental conditions' as those found in regulated American landfills (which are aerated). No research has been conducted regarding the leaching of this waste when it is randomly dumped in the Bengal basin, an ecosystem that is very different to an engineered American landfill.

PalT/Harbr designates and trains operators who are responsible for the management of the system in their area. Users pay a monthly or per litre tariff for access to the treated water, which is meant to cover all operational costs of the filter, including a wage for the operator.

Jadavpur University evaluated the performance and efficacy of 49 PalT/Harbr filters. The study found that the personnel entrusted with repairing and backwashing of the plants were irregular in attending to their duties, 80% of the systems have mechanical problems causing them to be non-functional and that 44% have been installed in areas where the arsenic content in the water is low enough that an arsenic removal system is not needed (Chakraborti, 2001).

2.1.5 All India Institute of Hygiene & Public Health - Jadavpur University (AIIH&PH)

Photo 1.7 AIIH&PH

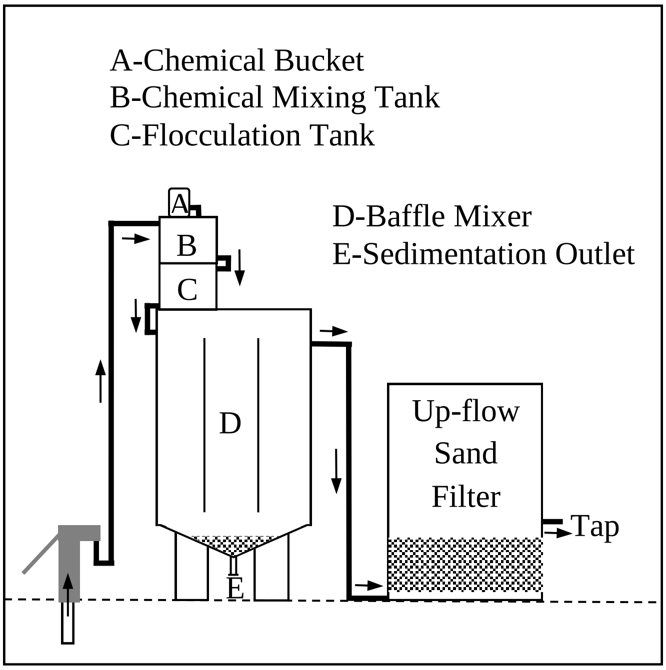

Figure 1.5 Diagram of AIIH&PH
(Modified from Ahmed et al., 2001)

Photo 1.8 Chemical buckets onto of the filter

Photo 1.9 Hole full of liquid waste

Professor Arunabha Majumder from Jadavpur University developed an arsenic removal technology in association with the All India Institute of Hygiene & Public Health. The Government of India provided the funds for several (5-6) of these units to be installed in the district of Murshidabad under the direction of the West Bengal Voluntary Health Association. The AIIH&PH system was given to the family who owned the land it was installed on, to be used as an entrepreneurial venture. After installation the family was responsible for purchase of the chemicals, maintenance and repairs as well as collecting a tariff from the villagers who use the filter. Three AIIH&PH filters were included in this study.

Sodium hypochlorite (used for oxidation) and aluminium sulphate (used for coagulation), are kept in buckets which sit on top of the system (Photo 1.7). Raw water is hand pumped into the top of the filter where both chemicals are mixed in. The arsenic-rich flocculants settle out of the system in the baffle mixer and during up-flow sand filtration (Figure 1.5). Majumder determined that the arsenic removal plant is effective in removing 90 percent of arsenic from tube well water which has initial arsenic concentrations no higher than 300ppb (Majumder, 2011). One major design flaw is that the buckets which hold the chemicals on top of the system are open to the atmosphere allowing for contamination of rainwater, bacteria, and debris (Photo 1.8). They are also not well-secured, and can be blown off the top of the filter on a windy day. One operator complained that he was unsure of the quantity of chemicals needed and how often. Another operator claimed the chemicals were too expensive so decided not to use them any longer. When the field team explained that not using the chemicals meant that this system no longer removed arsenic, he did not understand, claiming that the plant still works because the water still moves through the tanks.

There is very little literature published about the AIIH&PH and no literature on its waste products or waste disposal methodology. At the time of installation, a concrete-lined hole was dug beside the system, which was to be used for waste disposal. From field observations, liquid waste formed from backwashing and sludge collected from the sedimentation outlet were simply dumped into nearby ponds because the concrete-lined hole was full (Photo 1.9).

2.1.6 Central Glass & Ceramic Research Institute (CGCRI)

Photo 1.10 CGCRI

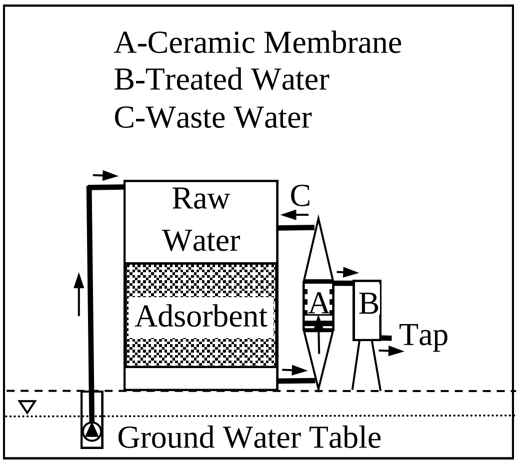

Figure 1.6 Diagram of CGCRI

The CGCRI is part of the Council of Scientific and Industrial Research which is an industry-based research and development organization in India. It is a private and for-profit institute that designed an arsenic removal unit using adsorption followed by filtration using a ceramic membrane. The Public Health Engineering Directorate (PHED), a department within the Government of West Bengal paid for four CGCRI filters to be installed. The household whose land was used as a site for building the system became the CGCRI's operator and owner. Each household was free to charge a tariff to community members to cover expenses and to promote it as an entrepreneurial venture. All four of these systems were visited and three were chosen to be evaluated in this study

CGCRI utilizes the principle of adsorption of arsenic by ‘nanocolloidal media’ likely to be comprised of ferric hydroxide (Roy et al., 2005; Bandyopadhyay et al., 2002). The particulate matter is then removed using a porous ceramic element which works as a membrane. The ceramic membrane replaces the sand filter component in other models (Figure 1.6; Photo 1.10). The CGCRI has kept all the details regarding the arsenic-removal mechanism and arsenic waste disposal as confidential proprietary information. One challenge when using a membrane is that electricity is required to maintain operation pressure. This adds to the cost of running the system and exposes the plant to the unreliable power grid causing the system to be offline very regularly and sometimes depressurising the system.

Another issue in this design is that membranes produce a large volume of waste water. The total amount of liquid waste and sludge generated, and how the CGCRI disposes of this waste, is information that is not publically available. During field observation, it was determined that waste water was cycled back into the system but the operators did not know anything about replacing the ‘nanocolloidal arsenic-removal media’. Operators were told to keep the sludge produced by the membrane in a barrel for CGCRI to collect at a later time. Operators estimate collecting between 20-50L of sludge per month. Two operators claimed to keep it in barrels and one admitted to dumping it into the nearby pond.

Villagers were generally unhappy with this business model. When one family who owned the CGCRI filter made enough money from it to build an extension onto their house, their neighbours became disgruntled. The neighbours felt it was wrong that one family could benefit financially from selling water. As a result, neighbours stopped using the filter and now the operator cannot make enough money from sales to cover the electricity costs.

2.1.7 Dug Wells through Project Well

Photo 1.11 Top view of a Dug well

Photo 1.12 Side view of a Dug well

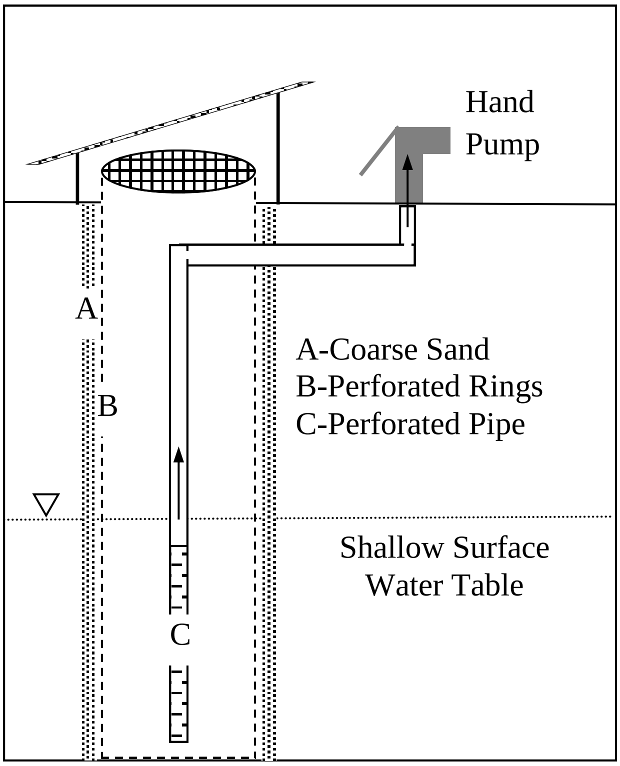

Figure 1.7 Cross section of a Dug well

Hand dug wells have been used across the world throughout history. The oldest known well has been found in an archaeological excavation in Israel dated to 8100-7500 BC. In India, the use of hand dug wells was mostly abandoned when tube wells became popular. Project Well and Aqua Welfare Society, are two NGOs that are working together to raise awareness of the feasibility of this technology as an arsenic mitigation solution in India. Through private donations, they have been able to construct around 250 dug wells since 2001. All recurring costs are covered by the NGOs allowing for everyone in the village to have unlimited free access to the water from the dug wells. Ten dug wells have been visited and three were chosen for inclusion in this study.

Hand dug wells target the shallowest of water from the unconfined aquifer closest to the ground's surface. This is the 'youngest' water that sits above the aquitard which below contains the Holocene aged arsenic-rich aquifer. Since arsenic is not present in this water, removal is not required, meaning no arsenic-rich waste is produced. However Dug wells can become contaminated with bacteria and debris from the surface. To minimise this possibility, Project Well has modified the traditional design to include a well cover and inside pipe that is directly connected to a hand pump at the surface.

The construction of the well begins with a hole being hand dug approximately 1m in diameter and between 7-10m deep (Figure 1.7; Photos 1.11 and 1.12). Perforated concrete rings are inserted from the bottom up with coarse sand placed in the annular space between the formation wall and the concrete rings. The coarse sand creates a highly permeable zone around the well that can function as a natural filter. The mouth of the dug well is built up to 45cm above the surface and is surrounded by a brick wall with a slanting roof, and is covered by a fine nylon net to avoid any external material from dropping into it. The roof is made of an corrugated tin sheet that is locked to avoid any tampering. A hand pump is attached to the well to draw out the water, preventing contamination by human contact. The dug wells are periodically treated with Theoline® which contains sodium hypochlorite (liquid bleach) that consists of 5% – 10% chlorine, 0.2% free alkali and water. 50g of Theoline® can disinfect 1000L of water (USEPA standard). In general practice, Theoline® is primarily used to control the odour and taste of water, and helps control bacteria. Theoline® is available in some medicine shops, is nontoxic and can be easily handled. Under the Project Well scheme, the family who owns the land on which the Dug well sits, is responsible for adding the Theoline® once every few months depending on the weather (Hira Smith et al., 2003).

2.2 Household-Scale Technologies

2.2.1 SONO 45-25

Photo 1.13 SONO 45-25

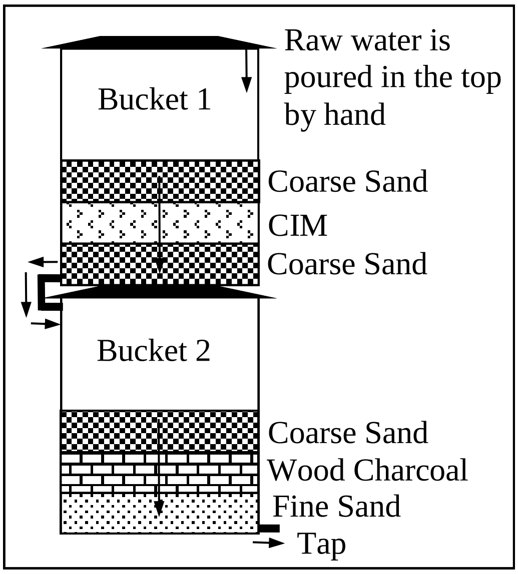

Figure 1.8 Diagram of the SONO 45-25

The SONO 45-25 was developed by a team of researchers at George Mason University USA, and Manab Sakti Unnayan Kendra, an NGO from Kustria in Bangladesh. It is widely used there and was verified through the Bangladesh Environmental Technology Verification – Support to Arsenic Mitigation (BETV-SAM) Programme in 2009. Filters can be purchased privately however are often given to families for free through NGOs. It is estimated that over 90,000 of these filters have been distributed in Bangladesh but only several hundred in West Bengal. In partnership with UNICEF and an NGO called Behala Sambit, a trial was conducted in one West Bengal village wherein 24 SONO45-25 units were installed and monitored for one year. The cost of the filter was subsidised by the programme where each household was only required to pay 100 Rupees for their filter. This village was visited and these filters were evaluated in this study.

Arsenic removal in this filter is done by running raw water through a composite iron matrix (CIM) which is made of cast iron. Manganese in the CIM catalyses oxidation of As(III) to As(V), and then the arsenic is removed by complexation on the surface of the iron matrix which is hydrate iron (FeOH). The filter consists of two plastic buckets (covered) placed one over another in a rack. These contain brick chips, layers of fine and coarse sand, wood charcoal and CIM (Figure 1.8; Photo 1.13). The buckets are connected with plastic tubing and have valve controls near the bottom. The process does not require any pre-treatment of water with oxidizing agents and does not require any maintenance, including no backwashing or regeneration of media.

The life span of the filter is less than two years. Once expired, the entire filter requires replacing. After the CIM is ‘saturated’ with arsenic, TCLP leeching tests show it to be not hazardous when disposed of in a controlled landfill. SONO 45-25 faces the same problem as the PalT/Harbr filter in that American TCLP leach tests may not apply in the Bengal setting. The field team observed entire SONO 45-25 filters, including the CIM randomly dumped in the local environment. Expiry dates were ignored as the household deemed them to be too expensive to replace.

2.2.2 Nirmal

Photo 1.14 Nirmal filter

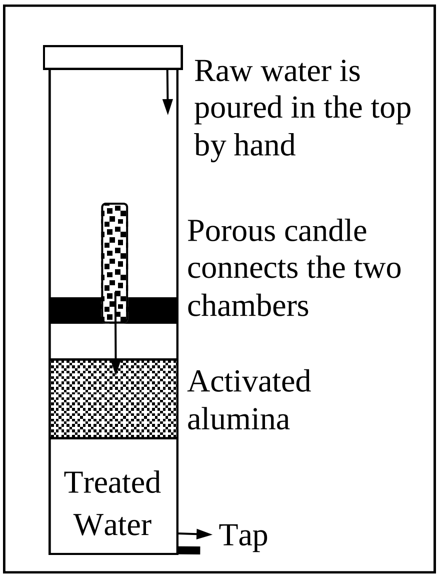

Figure 1.9 Diagram of the Nirmal filter

The ‘Nirmal’ filter was designed in collaboration with UNICEF and BESU using the same regenerable activated alumina as previously described in Section 2.1.3. The filter is available for purchase in Rural Sanitary Marts (RSM) across West Bengal for the price of 900 Rupees ($15 USD). RSM is an Indian retail outlet that manufactures and markets low-cost sanitation hardware. Nirmal was included in the same study as the SONO 45-25, in which UNICEF and Behala Sambit conducted a trial where 23 Nirmal filters were installed and monitored for one year. This village was visited by our research team and these filters were evaluated in this study. Two other villages had the Nirmal filters distributed by the Panchayat (Bengla word for local village government/elders). These two villages were also visited and included in this study. The entire cost of the filters was paid through the NGOs participating, with the expectation that each household would pay for the regeneration of the media once per year.

The Nirmal filter (Photo 1.14; Figure 1.9) consists of two chambers made of ‘ferro’ cement which are placed one over another with a rubber gasket in the middle to prevent leakage. Water is poured into the top chamber and moves through a filter candle which is fitted over the hole that connects the two chambers. The candle, made of burned soil and rice husk, removes iron from the raw water. The water then moves through a sachet of activated alumina (AA), which removes arsenic. The treated water sits in the bottom chamber ready to be poured through the tap (Bengal Engineering College, 2011).

The regeneration procedure for the AA is the same as in section 2.1.3, where each family is expected to bring the AA to a central regeneration facility once per year. However this was not done in any of the villages as people did not know how to contact the regeneration centre. As a result, households discontinued use of the filter after one year. The expired arsenic-rich adsorbent was dumped by each household in random locations.

One major complaint users had with the Nirmal was the very slow filtration rate. Users typically had to filter over night to have 10L of treated water ready for the morning. Since 10L of drinking water per day is not enough for a family, this raises the question as to whether the Nirmal is fit for purpose.

2.2.3 Defence Research and Development Organization (DRDO)

Photo 1.15 Pieces of the DRDO filter

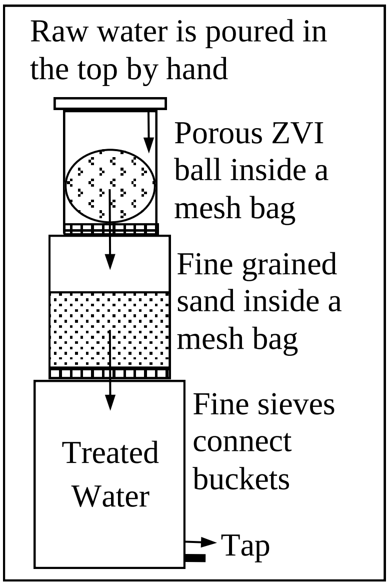

Figure 1.10 Diagram of the DRDO filter

Save the Environment NGO received funding through the Government of India, Ministry of Science and Defence to implement filters designed by the Defence Research and Development Organization (DRDO) to communities within arsenic-affected regions over three years. 2,100 DRDO filters were said to have been distributed free to each household during this time. Two villages, which were quoted as having 300 filters distributed in them, were visited for this survey.

The DRDO filter, removes arsenic by way of coprecipitation with iron and adsorption of this precipitate onto iron oxyhydroxides (Photo 1.15; Figure 1.10). This arsenic removal filter is built out of stainless steel and comprises three chambers. The iron-rich reactant material, which is zero valent iron (ZVI), is purchased from a local steel manufacturer, formed into a porous ball for easy handling, and enclosed in a fine cloth/net bag which is placed inside the first chamber of the filter. The second chamber contains sand that is also enclosed in a net bag, and the third chamber simply acts as a collector chamber for treated water. Water is meant to flow through this filter in as little as two minutes (Basu and Basu, 2012).

The arsenic-rich waste generated by this filter is mostly precipitate which is collected on the surface and inside the porous iron ball. Both the iron ball and used sand are meant to be collected by the NGO and turned into concrete bricks; however villagers were told by the local representative of the NGO to burn or bury the ball and dump the sand, which is what was observed in the field.

The iron ball needs replacing once every six months, and a representative from the NGO lives in the village and sells replacement nets and iron balls. However villagers complain that he changes the price depending on the buyer, and some are forced to pay an inflated price if they wish to continue to use the filter. Many households have refused to replace the nets and ball because of the inflated prices.

2.3 Summary

The ten technologies described in this chapter are all capable of delivering potable water with reduced arsenic content (<50ppb). However problems can arise when the technology is not operated as intended (chemicals not used properly, or adsorbents not regenerated, for example). In some cases it is clear that the technology could have been better designed to make it easier to operate and/or more durable. There may also be difficulties if the technology is deployed or managed in a way that does not match the users' needs or expectation. All the technologies had problems with safe disposal of arsenic rich waste, except for the Tipot and Dug wells (which produce no waste). Observations from field work and quotes by the stakeholders illustrate some of these problems, which are further explored in more detail in the chapters analysing the field survey.

3 Assessment Methodology

3.1 Evaluations

There are several review papers that summarize different remediation technologies available to rural communities in the Bengal basin (Ahmed, 2001, Saha et al., 2001; Sharmin 2001, Garelick et al., 2005; Malik et al., 2009). Due to the number of people being affected by arsenic poisoning, there has been an influx of novel technologies to the market in the Bengal region. As a result, there is now a need to have the ability to examine the technologies to determine which fail and why. An evaluation that could meaningfully compare technologies would be useful to policy-makers, technology designers, implementers and also for consumers, and both Bangladesh and West Bengal have created systems of evaluation which are described below.

3.1.1 BETV-SAM Program (Bangladesh)

The Bangladesh Environmental Technology Verification – Support for Arsenic Mitigation (BETV-SAM) program was collaboration between the Bangladesh and Canadian governments, funded through the Canadian International Development Agency. It claims to have developed a process for screening and validating the relative success of arsenic removal technologies. Certificates of verification were issued if the following criteria were met (OCETA/ETVCanada/BCSIR, 2009):

1) The technology treats water from each well to under 50ppb of arsenic;

2) The technology does not treat the water by adding any chemical at a concentration exceeding governmental regulation;

3) The volume of arsenic safe water produced by the technology is at least 70% of that claimed by the proponent;

The system claims that technologies get bonus points for being lightweight, being easy to use and for being inexpensive however the reports fail to explain the details of how the point system works and how each technology ranked within that point system. The criteria BETV-SAM uses to determine whether a technology should be available to use in the field is based purely on technical, geochemical and performance data. No environmental or sociocultural aspects of the technology are considered and very few economic factors are included. Sociocultural norms strongly influence the behaviours of people in this region (Mosler et al., 2010) and thus need to be considered when framing a technology from a sustainability view point.

3.1.2 Arsenic Task Force (West Bengal)

The report written by the Arsenic Task Force claims to identify available and appropriate technologies, discusses operational and maintenance issues, as well as identifying concerns that surround the monitoring and evaluation of different technologies (Government of India, Planning Commission, 2007). However this was not done in a systematic way with clear criteria. The report briefly lists and summarises the arsenic removal mechanism used by each technology and presents a few comments on it (maintenance or set-up or arsenic removal capacity). The report is really a summary or review paper, and cannot be considered a systematic evaluation.

3.1.3 Other Assessment Tools

Various other assessment tools are available, like Life Cycle Assessment, Ecological Foot-printing and various Impact and Risk assessments. Ness et al. (2007) summarise and categorise these and many more assessment tools by areas of applicability. These tools have very specific goals, none of which include a triple-bottom-line approach to product-scale assessment. The Global Reporting Initiative (GRI) is a network-based organisation that creates sustainability reporting guidelines for companies and institutions. Its framework is a standardised approach which determines principles and performance indicators that can be used to measure and report economic, environmental and social aspects of a specific industry, sector or organisation (GRI Portal, 2002). The European Environment Agency has adopted the use of a framework which distinguishes driving forces, pressures, states, impacts and responses (DPSIR) in its environmental reports. According to this framework, there is a chain that links these elements which can be used to describe the relationships between the origins and consequences of environmental problems (Kristensen, 2004). Neither the GRI reporting guidelines nor the DPSIR are appropriate for the problem outlined in this research. The assessment of an arsenic mitigation option requires a method that includes consideration of the degree to which it is designed to facilitate continued-use in a specific community.

3.2 Process Analysis Method (PAM)

The Process Analysis Method (Chee Tahir and Darton, 2010) is a way of analysing a system to generate a set of indicators which reflects the degree to which the system is sustainable. The Process Analysis Method (PAM) bears some resemblance to the DPSIR approach in linking cause to effect, but is simpler in not requiring a model of this linkage, which PAM achieves by focussing only on identified issues. The PAM is suitable for assessment of arsenic mitigation options because it describes how to build up an indicator set for a particular system using a transparent methodology with stakeholder involvement. Additionally, there is a strong connection between the PAM used on a product-scale and technology design theory. It has been applied to create a set of metrics which will describe the sustainability of each technology outlined in Chapter 2.

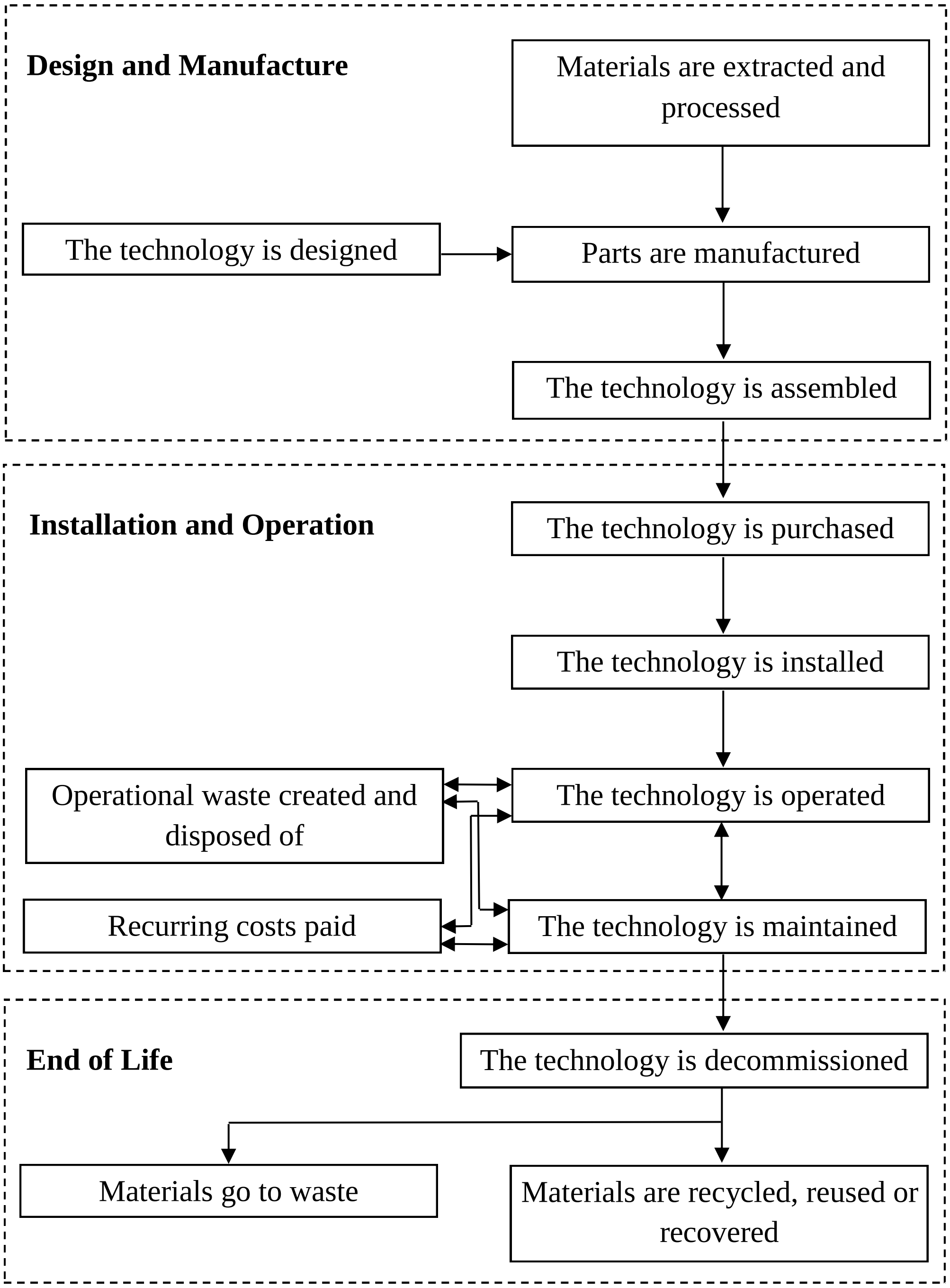

Figure 3.1 Arsenic mitigation as a system of processes (Etmannski and Darton, 2013).

The PAM is rooted in engineering systems theory. The system being considered (in this case, a technology application) is carefully surveyed and described as a set of processes (Figure 3.1); each process causes impacts which may be beneficial or detrimental in terms of sustainability; these impacts give rise to issues which are important for one or more stakeholders (impact receivers). The PAM creates indicators characterising issues, within the economic, environmental and sociocultural capital domains. Overall then, the set of indicators describes the degree to which the system is sustainable. Previously PAM has been used to select indicators to quantify the sustainability performance of business operations related to the palm oil industry (Chee Tahir and Darton, 2010) and of the UK transport system (Smith et al., 2013). Other projects in progress relate to the sustainability of large river basin management, and climate interventions (geoengineering). These are analyses of large complex systems, however PAM can be used in product assessment, as the framework is simple enough to allow for this flexibility, while still maintaining all aspects of its holistic approach.

3.2.1 Design Theory and PAM

Due to the emphasis of PAM on stakeholders (users), and it being triple-bottom-line and holistic analysis, it is easy to see how designers could use the PAM framework as a guide when engineering a sustainable product, or conversely, how well the PAM fits into the already pre-existing design theory literature making it a suitable choice in methodology for a sustainability assessment. The literature states that designing eco-friendly technology does not automatically lead to sustainable user behaviour (Derijcke and Uitzinger, 2006), especially if the sociocultural context of the user has not been considered. Several authors have discussed how product design can positively influence users. For instance, Jelsma and Knot (2002) applied the idea of ‘scripting’ to product design, by which they mean to design the product so as to guide the behaviour of the user to comply with values and intentions defined by the designer. According to this idea, features that promote sustainability should be built into the design to promote a change in behaviour. Thus the design of the product takes account of ways in which people use it, in order to reach a more sustainable result (Rodríguez and Boks, 2005). Smit (et al., 2002) describe ‘user-centred eco-design’, which is presented as a possible solution for reduction of environmental impact of products. This design method recognises that issues of behaviour, acceptance and desirability are rarely addressed in traditional eco-design. ‘User-centred’ design puts the user at the heart of the entire design process. Instead of focusing on technological possibilities and quality measurements in terms of components, it takes solutions that fit the user as a starting point and measures product quality from a user point of view (Vredenburg et al., 2002), taking into account needs, wishes, characteristics and abilities of the projected user group. The aim of adopting a user-centred design approach is to improve the quality of the interaction between the user and the product so as to induce sustainable behaviour. From the literature it is clear that there are several approaches possible to encourage more sustainable behaviour through appropriate product design. Such an approach to design requires a thorough understanding of human-product interaction. There is value in approaches that are considered to be user-focused, eco-friendly and that include the process of scripting or user-based design modifications where applicable.

PAM was chosen as a methodology for selecting sustainability indicators because it includes these qualities in its framework. For example, PAM considers the perspectives of stakeholders, particularly with regard to identifying issues. In this case, the user of the arsenic mitigation technology has been identified as the primary stakeholder (user-centred). Issues which arise from the actions associated with using a particular technology are recognized and then categorized within the different capital domains. Product designers can then look to these issues and the set of indicators when considering scripting or user-based modification and design. PAM was the best choice for methodology because of the direct connection of the results with product design theory and therefore will produce an assessment that has utility for policy-makers, product-designers and customers.

3.3 The Six Steps of PAM

The steps in the process analysis method are explained in detail in this section and illustrated in Figure 3.2.

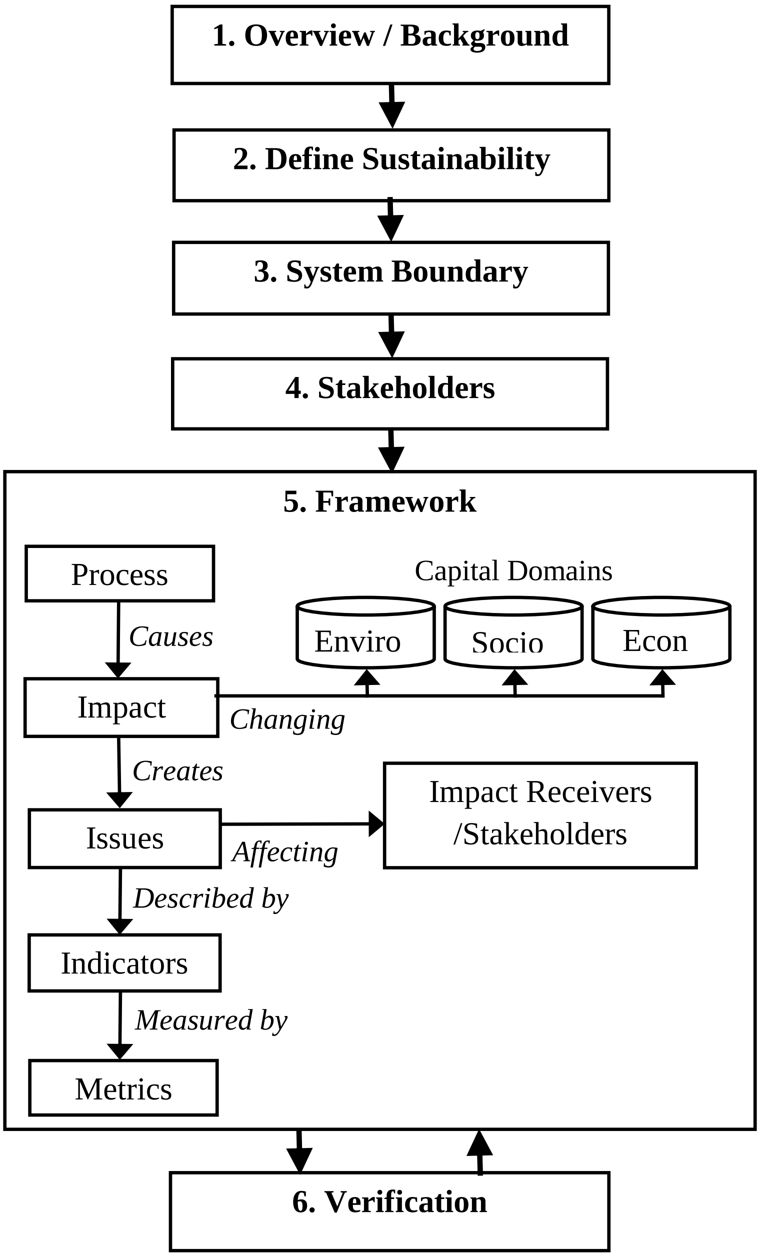

Figure 3.2 The PAM flow chart (Modified from Chee Tahir and Darton, 2010).

3.3.1 PAM Step 1: Overview of Background

The region of interest is the arsenic affected area in West Bengal, India, largely adjacent to the Ganges River and its tributaries. In total, 27 villages were visited, all located in four highly affected districts (Figure 3.3). Villages were chosen based on the presence of arsenic in the geographic area, mitigation options available in the locale, and the physical accessibility of a village for the survey team. See Chapters 1 and 2 for more details on the background of the region, arsenic problem and technologies profiled.

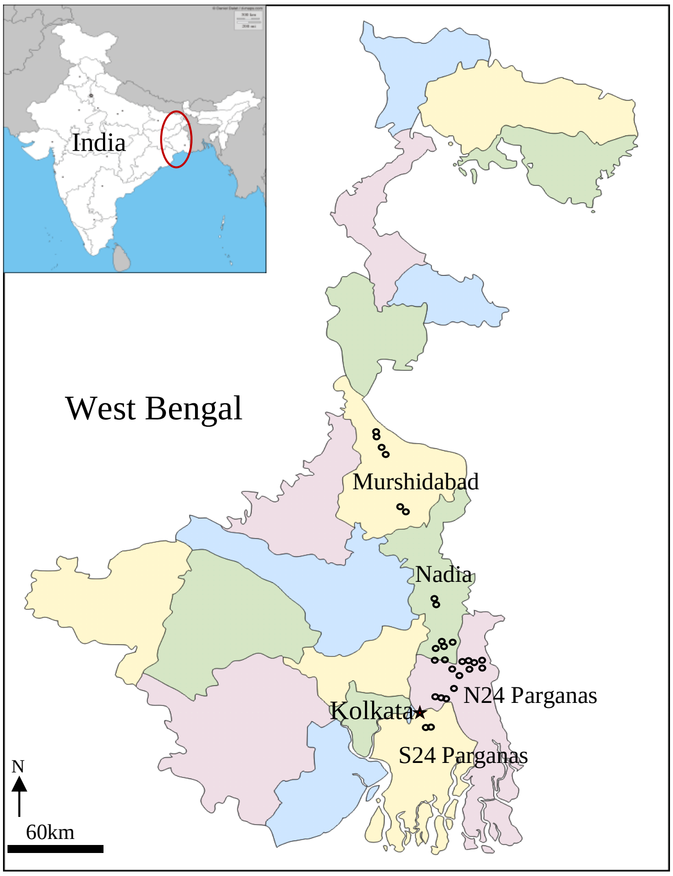

Figure 3.3 Map of West Bengal, India showing the locations of the 27 villages surveyed across four districts in relation to the capital city, Kolkata (Modified from Dalet, 2012).

3.3.2 PAM Step 2: Define Sustainability

The first step in the process of trying to measure sustainability, is defining the term. The idea of sustainability stems from the concept of sustainable development which was defined by the Brundtland commission to be: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and
- the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs."

(Brundtland, 1987)

Since then, there have been many variations and extensions to this basic definition and none are universally agreed on. There are many different views on what it is and how it can be achieved. The Brundtland definition is sometimes criticized as being too vague to be useful as it is subject to wide interpretation (Mitcham, 1995; Toman, 2009); however it is the openness of this definition that allows its widespread use in different contexts and at different scales. The concept of sustainability is commonly used to imply responsible and proactive decision-making, innovation that minimizes negative impact, and maintaining balance between social, environmental, and economic capital over time. Sustainability also encompasses many scales of time and space ranging for example, from the total carrying capacity of the planet to the sustainability of local ecosystems, and time scales from 'intergenerational' (meaning hundreds of years) to immediate impacts. It is therefore vital to define physical and temporal boundaries so that there is a clear understanding of the context and limits of the sustainability analysis.

Consistent with Brundtland, sustainability is defined in this context as arsenic mitigation technologies that are economically viable, environmentally responsible and socioculturally appropriate. Economic viability means that for all stakeholder groups, their ability to use and/or provide the technology is not affected by financial constraints, and does not diminish with time. Environmental responsibility requires maximum use of renewable or replaceable resources and materials, avoids production of waste that systematically degrades the environment, and which utilises a waste disposal methodology that minimises environmental and human exposure to harmful by-products. Socioculturally appropriate technologies gain the trust and confidence of users; they provide treated water acceptable in terms of taste, colour and odour; their operation is acceptably convenient to the user; in all aspects, the technology deployment recognises the level of awareness of the arsenic problem in the user community; and they are easy to use with respect to physical effort and skill level.

This work also considers the four Dublin Principles presented at the World Summit in Rio de Janeiro in 1992 as valuable to the approach of better understanding the system.

1. Water is finite and a vulnerable resource, essential to sustain life, development and the environment.
2. Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.
3. Women play a central part in the provision, management and the safeguarding of water.
4. Water is a public good and has both a social and economic values in all its competing uses.

3.3.3 PAM Step 3: Define Boundary

The system boundary is defined by the geographical extent of the arsenic-affected community utilizing the particular mitigation option. In most cases, such communities consist of approximately 100 neighbouring houses and/or the area within 1000m distance from the technology site (in the case of community systems). The temporal boundary is more difficult to define. The technologies are often not designed to last for more than ten years, however the arsenic-waste produced is present in the environment for much longer than this. Therefore the temporal boundary was chosen to be 50 years, which includes the effects of the dispersal of arsenic-waste across several generations while still being realistic about technological and design limitations.

3.3.4 PAM Step 4: Identify Stakeholders

The primary stakeholder in this research is the technology user. A questionnaire was developed (Appendix II) to explore the views of this stakeholder on various issues identified through literature and using the PAM framework. Following an initial (pilot) trip to India, the questions were adjusted based on observations and preliminary input from the technology users. A second programme of more extensive field work was subsequently carried out to collect the technical and sociocultural data needed to input into the modified framework. In addition to user-feedback, other stakeholder input was gathered from meetings and informal interviews with various levels of government, technology designers and field implementers/facilitators. These included the local *Panchayat* (village mayor) in every village visited, and the Bengal Chamber of Commerce and Industry, the State Water Investigation Directorate and the Institute of Environment Science and Wetland Management, Government of West Bengal (provincial level), and Department of Groundwater and Geology, Government of India (national level) who are the policy-makers and are often involved in developing long-term water-provision strategy for the West Bengal region. Meetings were also held with NGOs including UNICEF-Kolkata, Save the Environment, Behala Sambit, Aqua Welfare Society, West Bengal Voluntary Health Association and the Centre for Groundwater Studies, who are all involved in the implementation of arsenic mitigation technologies. Discussions were also held with technology designers from IIT-Bombay, Jadavpur University, Pal Trockner, Harbauer, Presidency University, and CGCRI. Obtaining feedback and insights from technology designers, implementers and local, regional and national level policy-makers was important in framing the problem, and in obtaining technological and economic-related quantitative data. These groups expressed interest in understanding how this research could aid in modification of design, implementation practices and/or policy-making for arsenic mitigation.

3.3.5 PAM Step 5: Framework

Following the principles outlined in the PAM, the next step is building a framework of issues and indicators (Figure 3.2). The capital domains utilised in the chosen definition of sustainability represent a triple-bottom line perspective. Next, identifying the impacts within the different domains arising from the actions associated with using a particular technology is required. These actions can be allocated to 'design and manufacture', 'installation and operation', and 'end of life' stages of use. Each action or impact generator is systematically examined to identify all the decisions taken, or policies implemented within the system that cause impacts on the three capital domains. If any impact generators affect the stakeholders, then they become impact receivers. Impact receivers are identified in order to ascertain the relevance of a particular impact. If no impact receiver can be identified then the impact does not warrant further attention. It is the concern of the impact receiver regarding a particular impact that constitutes an 'issue'. When the issues related to the impacts have been identified, they must be characterised in a way that quantifies the magnitude of the effect. This requires an indicator. It is important that the link between the issue and indicator be as direct as possible. In the final step, metrics are developed for each indicator to measure the severity of the impact on each capital domain.

For example, the action of disposal of the arsenic-rich waste product created by a technology during regular usage (impact generator) raises several issues. One issue, within the environmental domain, is the possibility of creating a point-source recontamination from disposal of arsenic-contaminated adsorbent. This could result in an additional route of exposure to the community (impact receiver) for example by contaminating soil that will be used for growing food. An indicator for this issue is: the amount of material (mass or volume) disposed of overtime and the expected or usual concentration (ppb) of arsenic contained within it. The metrics are the actual values determined for each indicator. It is the creation of the whole set of metrics that is useful, since it is the whole set, across all capital domains that quantify the sustainability of the technology. The result is a set of measurable indicators, that when taken together, directly quantify the issues.

3.3.6 PAM Step 6: Verification

After the framework is completed, it is necessary to verify the indicators and metrics, through further review and refinement. This iterative stage involved fieldwork, interviews and consultation with stakeholders to ensure that the analysis was as complete as possible – so that no important issues were missed out. The verification process continued until a satisfactory set of indicators and metrics were available for testing.

3.3.7 PAM Summary

The Process Analysis Method was chosen as a methodology for selecting sustainability indicators because it considers the perspectives of stakeholders, particularly with regard to identifying issues. In this case, the user of the arsenic mitigation technology is identified as the primary stakeholder (user-centred). Issues which arise from the actions (known as impact generators) associated with using a particular technology are recognized and characterized with indicators. Product designers can then look to these issues when considering scripting or user-oriented modification of their technology.

3.4 Indicators Generated through PAM

Tables 3.1, 3.2 and 3.3 show the framework created using the PAM and includes the verified indicators for all three capital domains used in this sustainability analysis. The metrics used for economic, environmental and sociocultural capital are a set of codes.

Coding refers to an analytical process in which data, in both quantitative form and qualitative (such as interview transcripts or questionnaire results) are categorised to facilitate analysis. Coding categories were devised according to the types of response gained for each metric. More details and the results for Sociocultural, Environmental and Economic capital are found in Chapters 6, 7 and 8.

Store of Value: Sociocultural					
Process	**Impact**	**Issue**	**EIR**	**Indicator**	**Metric**
Installation and Operation	Trust	Factors that encourage or discourage long-term use of the technology	User/ Community/ Future Community	Method of Engagement	Coded
				Behaviour of Local Leaders	
				Behaviour of Operator/ Supplier	
				Accountability of Operator/ Supplier	
Design and Manufacture	Confidence			Durability	
				External Appearance of Technology	
				Diarrhea Experienced after Ingestion of Treated Water	
Installation and Operation				Transparency of Finances / Costs	
				Proof of Regular [As] Testing / Certifications	
				Presence of Appropriate Signage	
	Convenience			Distance to As-free water	
				Duration of installation	
				Conducting maintanence	
				Hours treatment available	
Design and Manufacture				Flow rate of technology	
				Accessibility of replaceable parts	
				Purchasing made easy	
				Affected by power outages	
	Acceptability of Treated Water			Taste	
				Colour	
				Smell	
Installation and Operation	Awareness			Households' understanding of [As] in untreated water	
				Households' understanding of physical effects of As on health	
				Presence of Community arsenic awareness campaign	
				Presence of arsenic awareness programme in local schools	
				Degree of villagers' awareness of As in waste	
	Compatibility			Degree of Technical expertise required to install technology	
				Degree of Technical expertise required to operate technology	
				Degree of Technical expertise required to conduct maintenance	
				Level of physical exertion required to install technology	
				Level of physical exertion required to operate technology	
				Level of physical exertion required to conduct maintenance	

Table 3.1Impacts and indicators generated for the sociocultural domain.

Store of Value: Environmental					
Process	**Impact**	**Issue**	**EIR**	**Indicator**	**Metric**
Design and Manufacture	Resource depletion	Use of non-renewable, non-recyclable and non-reusable materials leave fewer resources available to meet future needs	User/ Community/ Future Community	Materials and energy used in construction	Coded
Installation and Operation				Renewable energy used	
	Ecotoxicity	Degree of risk of further human exposure either directly or indirectly and/or further point source environmental (water, air and land) contamination		Number of disposal locations - Back wash	
				Location of waste disposal - Backwash	
				Method of Disposal - Recontamination - Backwash	
				Number of disposal locations - Sludge	
				Location of As-rich waste disposal - Sludge	
				Method of Disposal - Recontamination - Sludge	
End of Life	Waste creation	Use of land for waste disposal		Aspect of regeneration, recycling, reuse	

Table 3.2 Impacts and indicators generated for the environmental domain.

Store of Value: Economic					
Process	**Impact**	**Issue**	**EIR**	**Indicator**	**Metric**
Design and Manufacture	Affordability	Possibly too expensive for stakeholders	User/ Community	Provision for users below local poverty line	Coded
Installation and Operation				Cost of purchase and installation	
				Provision of future capital for replacemnt purchase	
				Monthly tariff per household	
		Income may not cover all costs		Cost of replaceable / regenerable materials	
				Cost for power	
				Laboratory testing costs	
				Cost of transport / delivery	
				Amount operator is paid	
End of Life				Cost of disposal	

Table 3.3 Impacts and indicators generated for the economic domain.

4 Methodologies: Fieldwork and Data Analysis

Four months of field work was carried out to collect the data needed to input into the PAM framework. The methods used for data collection and analysis are described here.

4.1 Surveyors

The qualitative data was gathered by a team of surveyors who conducted household surveys and informal interviews. Careful consideration was given to facilitating the participation of all the households approached, and to limit survey bias. More specifically, the survey team's gender, ethnicity, language skills, level of expertise in sociology and survey protocols, and practical experience were all considered. A team of ten female social anthropologists was formed to carry out the surveys. Each surveyor had received her master's degree from the region's most prestigious university, The University of Calcutta, and was originally from the local area. The team was multilingual, each woman being fluent in Hindi, Bangla and English. Additionally, they each had previous practical experience in surveying and interviewing and attended a Training and Safety seminar facilitated by the Oxford team. The training seminar emphasized the need for surveyors to ask the set of questions exactly as written, in the correct order, in a neutral tone and not to suggest answers to respondents (known as leading). Once in a village, the surveyors worked in pairs, where one asked all the questions (in Bangla) and the other wrote down all the answers (in English). This was done for reasons of efficiency and safety. It also provided accountability by ensuring the questions were asked correctly and answers translated directly. The teams of two were mixed up daily to allow each surveyor equal opportunity to work with everyone in the group and to limit any inherent bias that might form within any one pairing. A few surveys (<10) were conducted in English entirely, at the request of the interviewee. The field supervisor checked the conduct of randomly selected interviews throughout each field-day to ensure that interview and sampling protocols were being followed.

4.2 Sampling of Population

The villages varied in both geographic and population size. Occasionally, villages would run alongside one another unmarked making it difficult to determine by simple observation where one village (*para*) begins and one ends. In small villages, the entire village was used as the sample, as they typically contained less than 100 households. In the cases of larger more amalgamated villages, the sample area was determined to be the 100 households nearest by proximity to the mitigation option in all directions. Out of each population (around 100 households in every case), 33-35 households were chosen to take part in the survey. This was done by randomly choosing one house in a cluster of three. To obtain a representative sample of differing economic and social groups, random sampling was strictly adhered to (United Nations Statistics Division, 2005). A total of 948 households were approached. The response rate was 98.4% with 15 households declining to answer the questionnaire. This resulted in 933 household surveys completed across the 27 villages, 1-4 villages per technology.

4.3 The Survey

The survey was created in English, translated into Bangla and back-translated into English to ensure there were no mistakes in the translation. Surveys can contain two types of questions: closed-format questions, where the respondents must choose from a choice of given answers and open-format questions, where the respondents are free to answer in their own words and style. The survey contained 120 questions and took on average 20 minutes to complete. The first 60 included both open and closed-format questions about current and past use of the arsenic mitigation option available in the village. These questions covered issues that fell into three stages of use, 'design and implementation', 'operation and maintenance', and 'waste and disposal'. The middle section of the survey contained 50 closed-format questions gauging the level of importance of all the various issues identified in the framework (for example, *How important is it to you that..*?). A five point Likert Scale (Bryman, 2012) was used to measure intensity of feelings about the issue in question. The final section consisted of ten open-format questions that explored the user's range of willingness (walking distance, monthly tariff, time spent queuing). Appendix II contains the English version and the data dvd for the Bangla version.

4.4 Informal Interviews

While questionnaire surveys are relatively easy to organize and prevent the personality of the interviewer affecting the results, they do have certain limitations. They are not suitable for questions that require probing to obtain more complex information, as they should only contain simple, one-stage questions (i.e. questions whose answers do not lead on to further specific questions). For this reason, surveyors were encouraged to engage in an unstructured interview after the face-to-face questionnaire was completed. Unstructured interviews follow a flexible format, allowing the interview to progress naturally as a comfortable conversation in order to get insights into the attitudes of the interviewee. These conversations and viewpoints were documented at the bottom of each survey (or back page).

4.5 Approach and Management of the Interview/Survey

When a house was approached by a survey team, whoever answered the door (regardless of gender) was asked to represent their household and be a respondent. In some cases the person who answered the door would suggest a different family member as a participant, but this was at the household's discretion. The survey team requested assurance that the participant was a resident of the household and over the age of 18.

There was only one respondent per questionnaire. After the participant was identified and informed consent was given (Section 4.6; Appendix III), the survey team often suggested moving to a private area to conduct the survey. This was done to minimise noise, and any possible distraction or external influence. Despite taking this precaution, if a survey team felt that an answer given by the participant was influenced by a particular situation or individual, the survey team indicated this on the survey by underlining the question, which was later omitted from the analysis to ensure unbiased responses.

4.6 Ethics

The study protocol was approved by the University of Oxford's Social Sciences & Humanities Inter-Divisional Research Ethics Committee on July 9, 2012 (Appendix III). Informed consent was obtained verbally from all study respondents and by the subjects in all of the photos included in this study.

4.7 Technical Data

Participant observation is a method of recording conditions, events and activities through looking and doing rather than asking. Observation can be used to record both quantitative and qualitative data. Technical information about each system was collected at each village through participant observation and direct measurement. This included flow rate, average time spent queuing, average distance walked by the user, system size and appearance, construction materials, existence of signage, and waste disposal methods. This information supplemented technical data available from literature sources. Any measurement involving time was taken using an iPhone stopwatch. Distance walked was determined by physically walking the distance (and back) and counting steps. Large steps were taken and estimated to equal 1m. System size was taken using a tape measure. Photographic evidence was taken for every mitigation option, including photos of all existing signage, which when written in Bangla was translated by the surveyors.

4.8 Arsenic Testing

4.8.1 Field Test Kit

Onsite arsenic testing of raw and treated water was performed, using Wagtech's Visual Colour Detection Kit (WVCD) which has a product code of WAG-WE10600 (Sankararamakrishnan, 2008; UNICEF, 2010). This method uses a reaction of hydride generation similar to that described in methods 3114B (Eaton et al., 1998). The WVCD kit requires the addition of zinc dust and sulfamic acid ($HOSO_2NH_2$) to the water sample. This reaction converts the inorganic arsenic present in the solution to arsine gas. The arsine gas reacts with a mercuric bromide test strip to form a yellow to brown-coloured compound (AsH_2HgBr). The amount of arsine gas (AsH_3) generated increases with the concentration of arsenic in the sample. The mercuric bromide strip intensifies in colour with the increase of arsine gas, thereby quantifying the arsenic concentration in the sample. The colour of the reacted test strips are then compared against a specific incremental chart provided with the kit. The increments (in ppb) coded on the chart were (from lightest to darkest) 10, 20-40, 50, 60-80, 100, 100-200, 200-300, 300-400, 400-500. Given that the colour coded indicator card only had colour for 10ppb and then a range for 20-40ppb (missing 11-19ppb), when the colour fell between those shades, >10ppb was recorded. Any result that was lighter in shade than the colour coded as '10' was recorded as '<10'. If no colour appeared, a value of zero was recorded.

In a typical analysis in the field, a glass flask was filled with 50mL of sample solution, placed on a firm surface, and a sachet of sulfamic acid powder was poured into the solution. Next, a sodium borohydride tablet was dropped into the flask and a bung device loaded with filter slides was immediately pushed firmly into the flask mouth.

According to the printed protocol, the reaction reaches completion after 20 minutes, at which point the appropriate filter is removed from the bung device, and its color matched to the color chart provided (Safarzadeh-Amiria et al., 2011). Van Geen et al. (2005) compared results obtained with the Hach EZ kit with those based on laboratory measurements for the analysis of the water from 799 Bangladeshi tube wells. They found that provided the reaction time was doubled to 40 minutes, the field kit results were accurate for 88% of the samples. The Hach EZ kit utilizes the same chemical reaction to obtain results as the Wagtech model except that hydrochloric acid is used instead of sulfamic acid. Therefore, double the recommended amount of time was allowed for each arsenic test to proceed to completion (40 minutes), to ensure more accurate results. The practice of doubling the wait-time to ensure completion when using these field test kits has been recommended by many researchers (Arora et al., 2009; Kinniburgh and Kosmus, 2002).

4.8.2 Laboratory Analysis

Ten samples were taken from nine different field locations as duplicates to be double-checked through laboratory analysis. Each sample was taken from the same source at the same time as the sample used in the field test. The water sample was poured into a 50ml plastic sample bottle (after being rinsed 3 times by sample water) and 2-3 drops of hydrochloric acid (HCl) was added immediately. The sample was sealed with a lid and stored in a dark space until they were all sent to Professor Dipankar Chakraborti’s laboratory in the School of Environmental Studies in Jadavpur University. The sample bottles, lids and HCl were provided by the laboratory.

The method used for arsenic analysis is a flow-injection hydride-generation, atomic absorption spectrometry system for the determination of arsenic in parts per billion levels in water samples (Samanta et al., 1999). Each sample was injected into a carrier stream of 5 M HCl by means of a six-port sample-injection valve fitted with a

50ml sample loop. The injected sample, together with a carrier solution, is met with a continuous stream of sodium tetrahydroborate. Mixing with sodium tetrahydroborate generates hydride, which goes through an ice water bath and then into the gas–liquid separator apparatus. Inside this apparatus, a continuous flow of N_2 carrier gas assists mixing and the reaction, and then carries hydride to the quartz tube mounted in the air–acetylene flame for atomic absorption measurement. Peak signals are recorded using a computer linked to the atomic absorption spectrophotometer. The peak height signals are measured and the concentrations of arsenite and arsenate are calculated against the individual arsenic species standard curves. The detection limit is 3ppb with 95% confidence. Thus below detection limit (BDL) from the lab analysis means arsenic may be present below 3ppb.

[As] (ppb) Tested by:	
Wagtech Kit	**Laboratory**
0	BDL
100-200	182
400-500	1080/1169*
<10	7
20-40	36
20-40	30
100	120
0	BDL
20-40	25

Table 4.1 Results comparing the field test kit samples with laboratory results.
*Blind duplicate sent to the lab

The laboratory results show a positive correlation to the duplicate sample field test kit readings (Table 4.1). For the third sample, there is discrepancy between the results from the field kit and the laboratory. The highest colour coded level on the field kit is 400-500ppb and therefore it is possible that the sample had higher concentrations of arsenic, as shown by the laboratory result (and duplicate sample).

4.9 Statistical Analysis

Upon returning from the field, the survey data was input into SPSS-IBM Statistical Software version 21.0 (Hilbe, 2003). The results from the survey included both ‘continuous’ and ‘categorical’ variables. Continuous results come in the form of a number (household income, respondent’s age, for example). All continuous results were input directly into the software. All information which resulted in categorical variables was coded and then input into SPSS. Coding involves converting all answers into a numerical value. The three types of categorical variable include: nominal, which are answers without an intrinsic order (like blue, red or green as options); dichotomous, which only has two options available (like male or female); and ordinal, which contains categories of choice that can be ordered (like strongly disagree, disagree, neutral, agree, strongly agree).

The information for each household was input separately and then categorised by village and technology targeted. The analysis for continuous and ordinal variables included mean, median, mode, standard deviation, variance, range, minimum values, maximum values, missing values, and 95% confidence intervals. Statistical significance is the probability that an effect is not likely to be due to chance alone. To determine statistical significance between continuous and nominal variables, a chi square goodness of fit test was used. When comparing the correlation between two continuous variables, a Pearson Correlation was conducted when both variables were normally distributed and a Spearman Correlation was used when one or both variables were not normally distributed or when comparing continuous and ordinal variables. These tests result in a P-value, or calculated probability, which always falls between one and zero. The P-value is the estimated probability of rejecting the null hypothesis of a study question so when that hypothesis is true, the closer the P-value is to zero and thus the more significant the result. Conventionally, 5% (less than 1 in 20 chance of being wrong), 1% and 0.1% ($P < 0.05$, 0.01 and 0.001) levels have been used to indicate statistical significance. An Anova Test was used to compare the variance between groups of continuous variables (like to compare the means of three or more variables). Logistic

Regression was utilised when the dependent variable was nominal and the independent variable continuous. No dichotomous variables were identified and no transformations were needed.

4.10 Discussion

4.10.1 Gender of Surveyors

Gender is one of the most easily identifiable interviewer characteristics, and several gender-effects studies have concluded that female interviewers are more likely than males to result in respondents answering more frankly and honestly (Benney et al., 1956; Axinn, 1991; Blanc and Croft, 1992; Becker et al., 1995; Bignami-van et al., 2003; Weinreb, 2006). Benney et al. (1956) analysed combinations of gender and age of interviewer and respondent in sensitive areas of communication (sex habits). It was concluded that male interviewers obtain fewer responses than female interviewers. Similarly, data from a study in Nepal featuring the random assignment of interviewers to households was used to test several hypotheses regarding the influence of interviewer gender (for both male and female interviewees) (Axinn, 1991). Economic activity and fertility within the household were the topics of the questions in the survey. The results showed that interviewer gender does affect responses, with male interviewers generally under-reporting. Under-reporting means that respondents were unwilling to answer as many questions in a survey, compared to the participants interviewed by women. It also refers to the answers specifically. For example, the respondents interviewed by men provided significantly more negative responses to questions where positive answers might be viewed as less socially acceptable, and reported fewer numerical values in reference to household economics. It was concluded that potentially sensitive questions may be less threatening when asked by a woman in the Nepali cultural context and thus the use of female interviewers may help to reduce error in applications of surveys in other less-developed settings similar to Nepal. It is for this reason that the entire survey team in our research was composed of females.

4.10.2 Interviewer Bias

Religious beliefs of individuals were not considered during the hiring process of the survey team. All ten women hired happened to be Hindu. The villages surveyed were often homogenous in religion, with a majority of population being either Muslim or Hindu. No previous knowledge of religious practice was available before entering any specific village although it was identified through observation quickly upon arrival, as Muslim women cover their heads in public with a scarf or sari. When women in public did not have the heads covered, it was assumed that the village was Hindu which would be confirmed once teams entered homes and saw religion-specific icons. It is possible that people in the village could be any religion as it was not a question included on the survey. One village in particular was identified as following a rare tribal religion. The most recent Indian census shows that 80.5% of the population is Hindu, 13.4% Muslim, and 2.3% Christian (Government of India, 2011). In this research, 63% of the villages visited during the fieldwork were exclusively Hindu, and 30% were exclusively Muslim (Table 4.2).

Before conducting fieldwork, no consideration was given to the possibility that religious beliefs might influence survey results, as it is not a common theme in literature or standard practice. However during the fieldwork period, it became apparent that prejudices existed in the survey team. It is likely that the religious backgrounds of both interviewers and respondents will have been evident to both parties. The surveyors were told to be as neutral as possible in their approach towards villagers, regardless of religion and a neutral attitude was always observed in the supervisor. No literature could be found on survey error resulting from religious differences. Given that the topic of research is arsenic mitigation and does not relate to religion in any way, it seems probable that the survey team was professional and unbiased in administrating the questionnaires and that the respondents gave answers unaffected by any religious differences. The very high response rate (98.4%) does not suggest reluctance on the part of the households to engage with the survey team. Precautions used to avoid interviewer bias included the significant reliance on scripted questions in the survey, monitoring of the interviews by the supervisor and regular switching of the surveyor pairs.

Technology	Village Code	Religion
Tipot	1.1	Hindu
	1.2	Muslim
IITB	2.1	Hindu
	2.2	Muslim
	2.3	"Tribal"
BESU	3.1	Hindu
	3.2	Hindu
	3.3	Hindu
PalT	4.1	Hindu
	4.2	Hindu
Harbr	5.1	Hindu
	5.2	Muslim
AIIH&PH	6.1	Hindu
	6.2	Muslim
	6.3	Muslim
CGCRI	7.1	Hindu
	7.2	Mixed
	7.3	Muslim
Dug	8.1	Hindu
	8.2	Hindu
	8.3	Hindu
SONO 45-25	9.1	Hindu
Nirmal	10.1	Hindu
	10.2	Muslim
	10.3	Muslim
DRDO	11.1	Hindu
	11.2	Hindu

Table 4.2 Religious affiliation (by observation) of villages surveyed.

5 Survey Results

This chapter presents an overview of the survey results and attitudes to technology provision, dealing with the major issues of population demographics, technology use, arsenic exposure and issue ranking.

The respondents comprised 629 women and 304 men (67.4% and 32.6%). The average number of people per household is 4.8, and average number of children (younger than 18 years old) per household is 1.1. These family-size values are the same as another survey conducted in West Bengal in 2012 which found that the average family had five members (Das, 2013). The median distance households travel to obtain drinking water is 200m. In 71.8% of responding households, an adult woman is responsible for water collection and in 24.8% of households, an adult male normally collects it. In the remaining 3.4% of households, children collect the drinking water. Collection occurs on average 1.6 times per day with a median of one occurrence per day. 59.7% of households learned about the mitigation option through word-of-mouth while 23.4% were informed by a door-to-door announcement from a representative involved with the technology implementation or operation. 11.2% of households discovered the mitigation option by observation and self-initiative while the remaining households heard about the technologies during a community meeting (2.9%), or through television advertising (2.8%).

5.1 Household Income

The villages which use the mitigation options designed by BESU and PalT/Harbr are shown in the survey (Figure 5.1) to have household incomes that are overwhelmingly statistically significantly higher than the other villages (p-value of 1.97E-9; Section 4.8). This result could indicate that those technologies have been targeted at richer communities, or that only the higher income communities could afford those more expensive technologies. The relationship between success of a mitigation project and economic factors is explored further in Chapter 8.

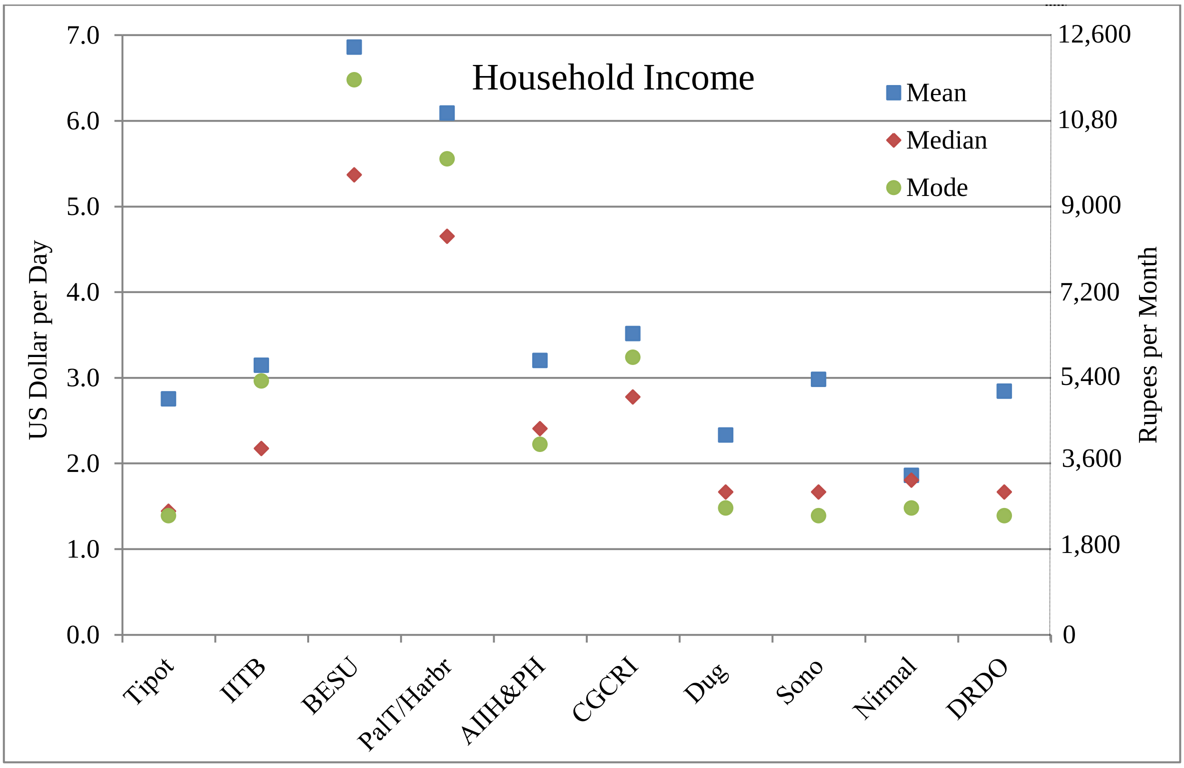

Figure 5.1 Mean, median and mode household incomes across villages that use each mitigation option (n=933).

In every village, the mean household income is higher than the median and mode which indicates that there are a few households with very high income. For this reason, the median is a more meaningful measure of village income. The median household income for the 933 households in this study is 4500 Rupees/month ($75) which is $2.50/day. Das (2013) reported that 56.5% of 200 rural respondents have an income of less than 2000 Rupees/month and 41% have an income between 2000-6000 Rupees/month. Das surveyed fewer households and only within the district of Murshidabad, whereas this study included Murshidabad and three other regional districts: N24 Parganas, S24 Parganas and Nadia. Other studies from West Bengal have been criticised for under-reporting incomes (Bakshi, 2008). In these previous studies, it is possible that results were biased due to the influence of interviewer gender (Section 4.9).

5.2 Household Education

The level of education within a household is one of the primary determinants of its income and level of poverty (Naschold, 2012). Individuals with higher level of education are more likely to obtain full-time jobs than others, resulting in higher household incomes (Figure 5.1). Villages with the highest median household incomes thus also have more households containing high school and college graduates (Figure 5.2). Among the 13% of households in the total sample that do not have a single literate adult, the median income is only 2,500 Rupees/month. In contrast, among the 16% of households with at least one college graduate, the median income is 10,000 Rupees/month —four times the median income of illiterate households.

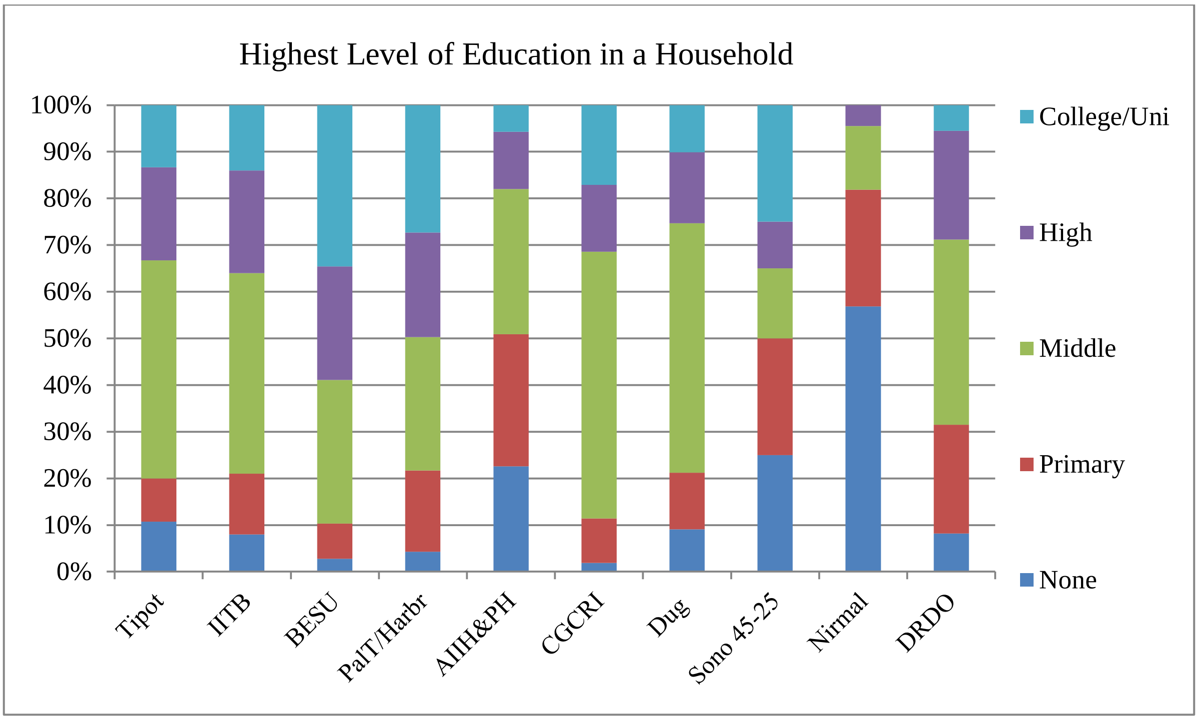

Figure 5.2 Average distribution of different education levels across villages that use the mitigation options.

5.3 Technology Use

Although the majority of households in every village are unsure if their own household shallow tube well contains arsenic, some households choose not to drink water straight from their household shallow tube wells, and have found an alternative. This behaviour is in line with the Health Belief Model (Janz and Becker, 1984) which attempts to explain why people will take action to prevent a potential health outcome. This model assumes that if individuals view themselves as susceptible to a health outcome, and believe that the consequences of having the health outcome are severe, and believe that there is a course of action available to them to reduce susceptibility or severity of the health outcome, and believe the benefits of this course of action outweigh the barriers, they are likely to take this action to reduce their health risk (Glanz et al., 2008).

Figures 5.3 and 5.4 when viewed together give an overview of how the villagers source their water. All the community-scale arsenic-removal systems are connected to Public Shallow Tube Wells, so the per cent 'use' highlighted in blue in both Figures 5.3 and 5.4 are similar for the first six technologies. There are often shallow tube wells that are considered to be on public land which are also used, which accounts for small differences between the two charts. The areas shaded red in Figure 5.3 indicate where no filter is used but a different arsenic-free alternative is used which is detailed in Figure 5.4. In the communities where they are used, IITB, BESU, PalT/Harbr and Dug Wells are used by over 50% of the villagers. Both villages surveyed in which the Tipot is located have a Public Deep Tube Well that most people use instead of the Tipot technology even though the Tipot is located more centrally and the villagers have to walk significantly further to use the deep tube well water. When tested, these deep tube wells proved to be arsenic-free. The villages in which the AIIH&PH, CGCRI, and Nirmal technologies are available, are of concern because many households (38-82%)

continue to drink untreated water from their (likely contaminated) Household Shallow Tube Wells.

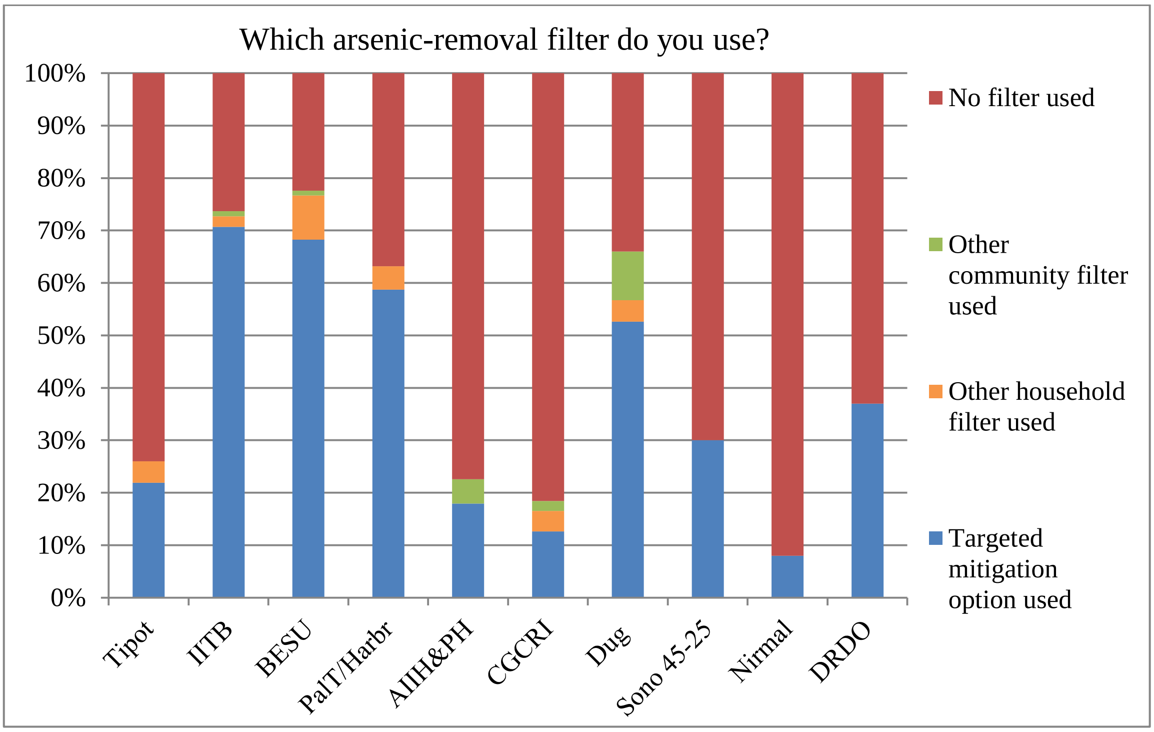

Figure 5.3 Average distributions of mitigation options used in the villages surveyed where particular options are targeted.

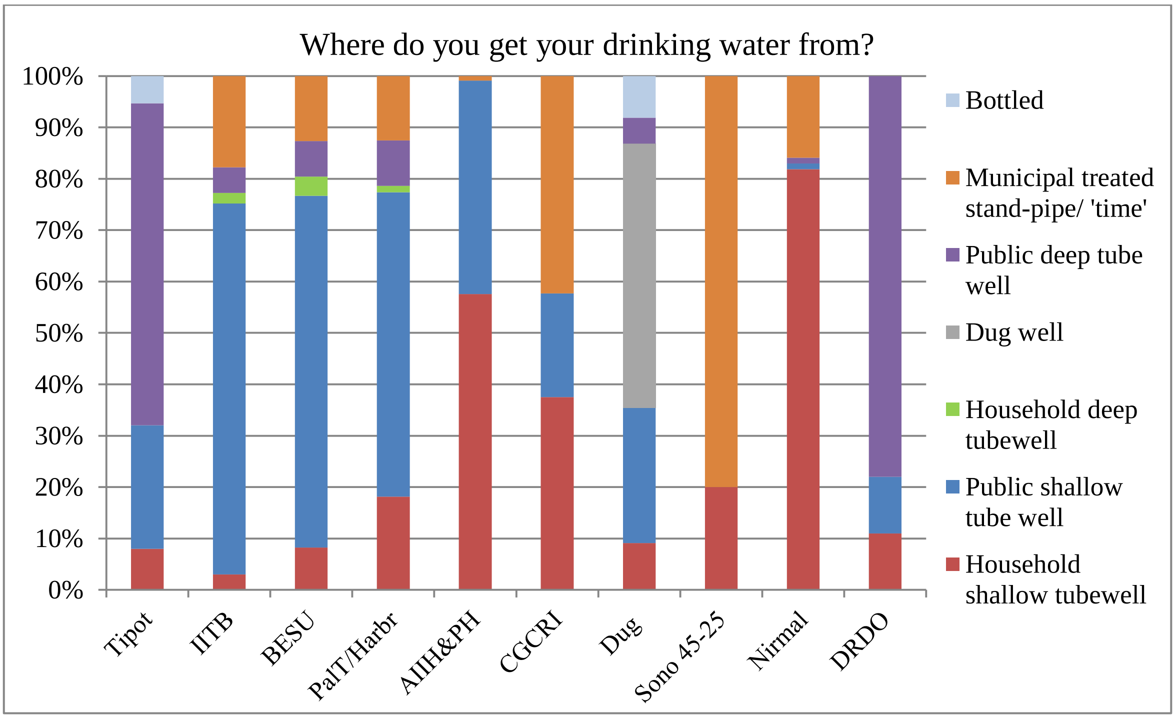

Figure 5.4 Average distributions of household water source.

Another conclusion drawn from Figure 5.3 is that the majority of villagers will all use the same filter or no filter at all. This is likely because the systems in place have been implemented through a government or NGO programme with significant subsidies. The use of another technology would have to be at the household's expense. Given this finding, this thesis will refer to villages by the technology utilised by most of people (for example, a 'Tipot village', or 'BESU community').

The two villages that had access to the DRDO household model mostly rely on a Public Deep Tube Well (PDTW) which was sunk by the Government of West Bengal. However the government abandoned this large-scale project before completion, without giving the villagers a reason. The local people have since connected power to the system to draw water from this well, thinking that it must be safer than their household shallow tube wells. Field tests showed the arsenic concentration in this PDTW to be 50ppb, which was the same concentration as some of the local household shallow tube wells. This case demonstrates that it cannot be assumed that a PDTW is an arsenic-safe option just because the majority of the people use it. Only by testing can one be sure that a well is safe. Relying heavily on municipal-treated water is also not ideal for villagers. It is nicknamed 'time' water because it flows irregularly throughout the day, sometimes for several hours at a time, and sometimes for only one. This becomes a large burden on households who rush to queue up to obtain their daily drinking and cooking water when 'time water' is turned on by a distance municipal government.

5.4 Exposure Profile

Figure 5.4 shows that 26% (N = 933) of households continue to use household shallow tube wells as their primary source of drinking water despite having access to arsenic-safe drinking-water options. Johnston et al. reported 62% (N = 1268) of households surveyed in Bangladesh to not use an arsenic-free water source despite having access to one (Johnston et al., 2013). Clearly, if more people would use the arsenic-free options which are accessible to them, the exposure would be reduced. Households using an arsenic mitigation option, buying bottled water, using a municipal water source or a PDTW thus constitute 74% of the total sample. These sources are widely believed to be either arsenic-free or containing arsenic below the national limit of 50ppb (Figure 5.5). They are thus deemed ‘safe’ by local regulatory bodies. This assumes that all mitigation options used are functioning correctly. However, results from the arsenic field tests (Table 5.1) show that only three mitigation options (Tipot, PalT/Harbr, Dug) reduce the arsenic concentration to less than 10ppb which is the international standard. By simply changing the limit, the results showing the percent of households drinking ‘safe’ water changes drastically (Figure 5.6). This is an example of how estimates of ‘affected population’ (Section 1.2) can vary so widely. Using the exposure results from this sample and extrapolating to the population of the Bengal Basin, which is estimated at 230 million (IIBB, 2010), results in 59.8 million people affected by the problem using 50ppb (26%) and 167.9 million using 10ppb (73%). Analysis in Table 5.1 show that in many of the villages, drinking water from shallow tube wells without using a properly operated filter exposes the consumer to a significant risk of arsenic poisoning.

Technology	**[As] in Raw Water (ppb)**	**[As] in Treated Water (ppb)**
TiPOT	n/a	0
IITB	100	>10
BESU	200-300	>10
PalT	20-40	0
Harbr	10	0
AIIH&PH	60-80	>10
CGCRI	100	>10
Dug	n/a	0
Sono	50	>10
Nirmal	20-40	>10
DRDO	50	>10

Table 5.1 Analyses of raw and treated water for all mitigation options using the Wagtech field test kit (Section 4.7.1).

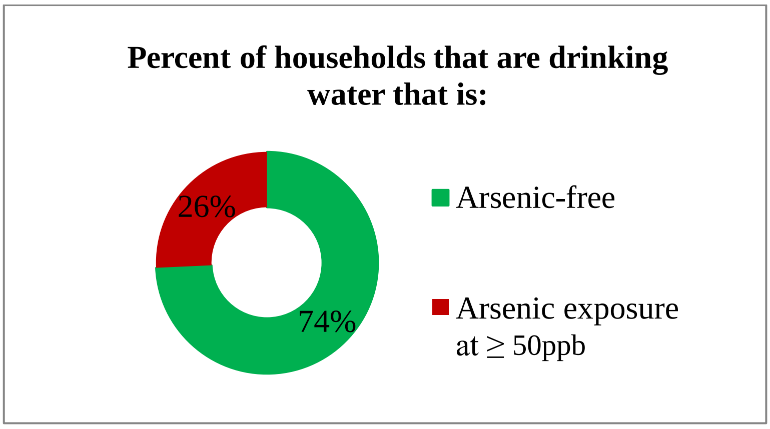

Figure 5.5 Distribution of households in the entire sample drinking 'safe' water, based on the local limit of arsenic in drinking water at 50ppb. 'Arsenic free' includes all the users of the mitigation technologies, 'time water', bottled water, and deep tube wells (n=933).

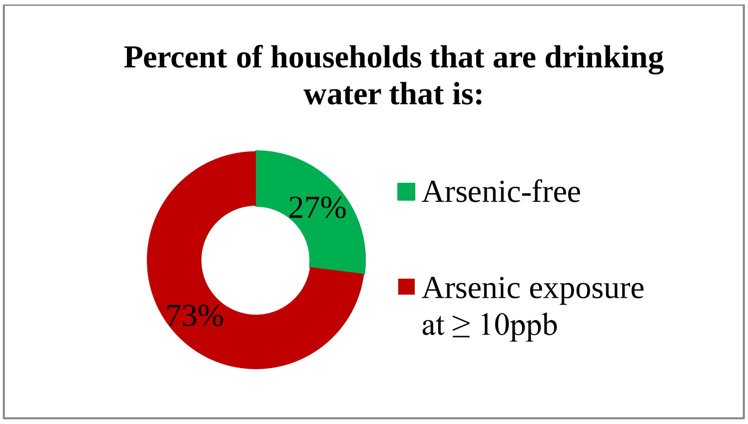

Figure 5.6 Distribution of households in the entire sample drinking 'safe' water, based on the international drinking water limit of 10ppb. In this case, arsenic-free only includes the mitigation options that tested to below 10ppb, 'time water', bottled water, and tested deep tube wells (n=933).

5.5 Importance of Issues

The issues identified through PAM (Section 3.4) were used to create questions included on the questionnaire, allowing villagers to choose each issue's degree of importance. The mean response to each question with a 95% confidence interval (from the entire sample; n=933) is ranked in Figure 5.7. The results of this ranking are used to weight indicators in Chapters 6, 7 and 8. Below is a description of the issues identified in each question and their degree of importance.

A - Issues that were found to be ‘Very Important’:

Cost (Q72, Q93, Q60); trust (Q86); distance to the filter (or home delivery) (Q77, Q57, Q57); understanding effects of arsenic on health (Q73).

B - Issues that were found to be ‘Important’:

Participation in decision (Q53); proof of regular testing (Q79, Q63); reliability of arsenic removal (Q61); environmentally friendly design (Q54); clarity of treated water (Q76).

C - Of the issues ranking between ‘Important’ and ‘Neutral’, the following were more important:

Process of engagement (Q51, Q52); operator having been trained (Q69); size of unit (Q55); rate of filtration (Q58); clarity of treated water (Q100); smell of treated water (Q66); location of arsenic-rich waste disposal (Q81, Q82).

D - Of the issues ranking between ‘Important’ and ‘Neutral’, the following were less important:

Duration of installation (Q71); materials of construction (Q56); presence of appropriate signage (Q89); household scale vs. community level (Q88); transparency of financing and costing (Q92); operator being paid (Q68); ability to hold operator accountable (Q70, Q74); need for the user to understand the maintenance procedure (Q67); taste of treated water (Q65, Q75, Q94, Q99); amount of municipal waste generated (Q80, Q83).

E - Issues that were found be ‘Neutral’:

Use of power vs hand-pump (Q96); need for the user to understand the installation process (Q59); need for the user to understand the operational details (Q64); trust of outside groups suggesting a technology (Q102).

Issues that were found be between ‘Neutral’ and ‘Unimportant’:

Use of chemicals or medicine in water treatment (Q91).

No issues were deemed ‘Unimportant’ or ‘Very Unimportant’

Section 5 of the questionnaire is listed below (Appendix II). The questions are about clean water technologies/systems in general. The point is to identify how important or unimportant certain values and criterion are to the stakeholder. The interviewees responded using the Likert Scale:

Very Unimportant	Unimportant	Neutral	Important	Very Important
1	2	3	4	5

How important is (it to you)…

51 to be consulted before the installation process?
52 to actively participate in the decision-making process?
53 for someone in your household to participate in the decision?
54 if the system is designed in an environmentally friendly way?
55 the system's size or area?
56 the type of materials used in building the system?
57 the distance the system is from your house?
58 the rate (or speed) that the system produces clean water?
59 to understand the installation process?
60 that clean water is affordable?
61 that the system is reliable?
62* to be given several options when choosing a CWT?
63 that the quality of water is tested regularly?
64 to understand how the system operates?
65 if the cleaned water tastes slightly bad?
66 if the water smells odd?
67 to understand the maintenance procedures?
68 that the person doing the testing/maintenance is paid?
69 that the person doing the testing/maintenance is trained?
70 to have the ability to hold the maintenance person accountable?
71 that the system is installed as quickly as possible
72 that clean water is free?
73 that your household understands the physical effects of Arsenic in water?
74 if the maintenance person does not have a boss or supervisor?
75 if the cleaned water has a strong taste?

76 that the water is perfectly clear?

77 that the system is very near your house?

78* if you have to conduct small repairs on the system?

79 to know the arsenic concentration in the treated water?

80 the amount of waste or sludge generated by the system?

81 if waste or sludge is dumped near your house?

82 if waste or sludge is dumped near the water source?

83 if there is an aspect of recycling or regeneration in the system?

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

84* I prefer the size of the CWT to be as small as possible

85* I prefer the CWT be constructed with recycled materials

86 Trusting the system and those involved with it is important

87* Those who can afford to pay for water should pay a clean water tariff

88 I prefer having a personal CWT inside my home rather than using a comm

89 All systems should have informative signs

90* I do not want to maintain my own water filter

91 Using chemicals or medicine to make water safe is bad and undesirable

92 I want to have access to all the financial details involving the system

93 Water should be free for everyone

94 I am willing to drink water with a slight taste as long as it's safe and clean

95 Having water delivered or piped to my home is the most ideal option

96 I feel that a CWT that uses power is not reliable

97* I do not care if a CWT creates Arsenic rich sludge or waste

98* I do not worry about where Arsenic rich sludge is dumped

99 Clean water should have no taste

100 I will only drink water that is clear in colour

101* I am willing to walk a short distance to get clean water

102 I would typically trust groups from outside my village who suggest CWT

*omitted from analysis

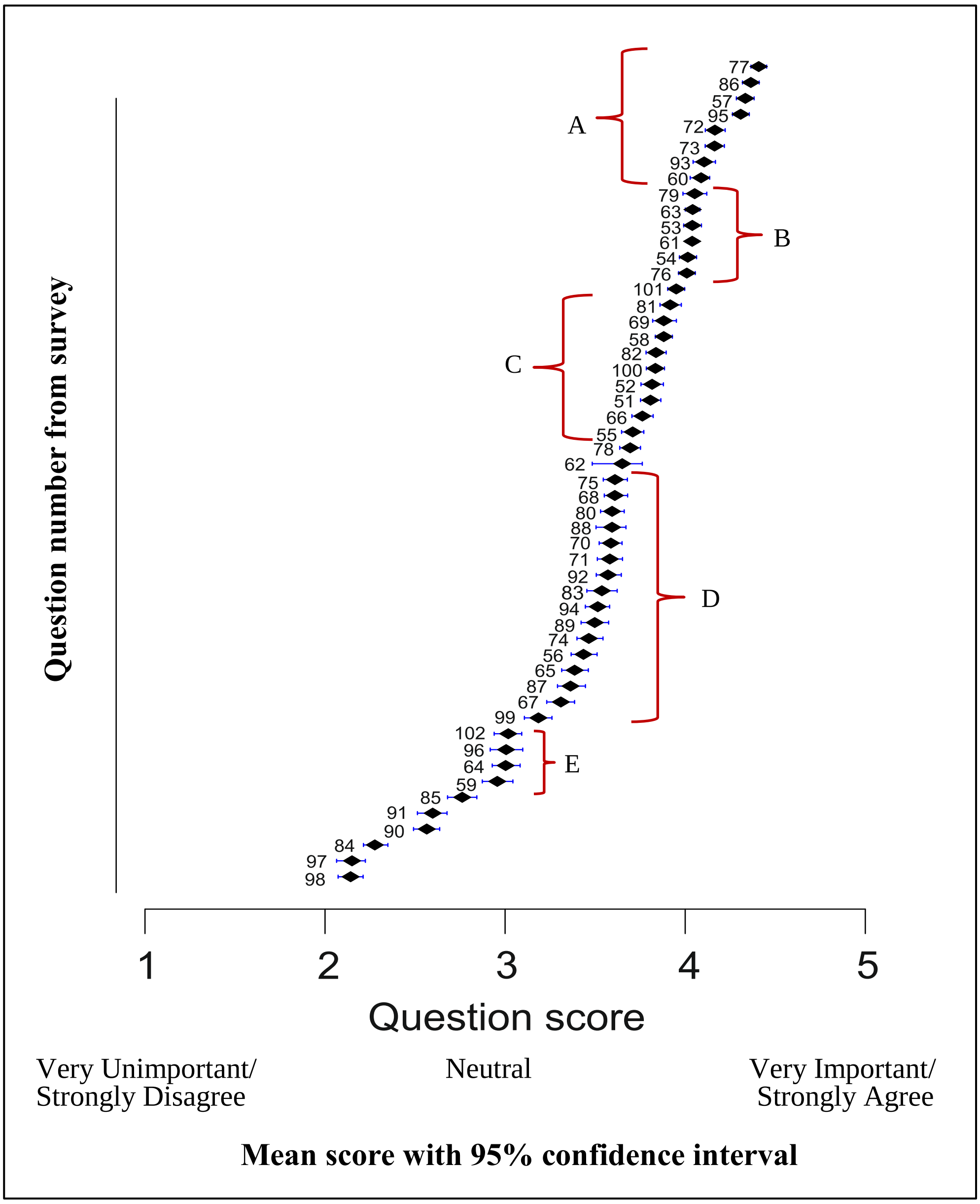

Figure 5.7 Mean scores with 95% confidence interval of every question from the field survey requiring the households to rank the importance of various impacts (Section 3.4).

Note that questions (Q) 62, 84, 85 and 90 have been omitted in the analysis due to lack of clarity in the question: the question contained concepts or assumptions that were not understood, or the phrasing was unclear. Q101, Q78 and Q87 have been omitted from this list as the questions do not represent an issue listed but rather actions the user are willing to engage in. Answers to these questions were used to gain perspective on user’s levels of willingness to have a multi-tiered price for treated water

(Q87), willingness to walk to collect water (Q101) and willingness to conduct repairs (maintenance) on a system (Q78). Q97 and Q98 are repeats of questions asked earlier (Q80, Q81) but phrased in a negative way and thus also omitted. Negatively phrased questions are meant to result in a response opposite in the scale from the positively phrased questions, which is used to confirm that the respondent is engaged in the questioning process (and not just answering ‘agree’ or ‘important’ to everything) (Bryman, 2012). In some cases, there are multiple questions asked about the same issue (like ‘cost’) but phrased in a different way. This is another tool used to ensure consistency in response by the participant (Bryman, 2012). In all cases, the duplicate questions fell into the same level of importance except for the issue of ‘clarity of treated water (Q76, Q100) which were ranked slightly different, placing it at both ‘B’ and ‘C’ level.

The results presented in Figure 5.7 demonstrate that the villagers determined the four most important issues to be considered are cost, trust, distance to the filter (or home delivery) and understanding the effects of arsenic on health. This result is used later in the analysis to determine relative weighting of indicators. It also highlights possible differences in priorities between the users and the technology designer/implementer, as public health and awareness campaigns are not included as part of the system. Additionally, designers and implementers typically consider environmental aspects relating to the technology, which is not of significant importance to the user in this region. Finally, it is not standard practice to engineer a technology in a manner which might increase trust and confidence in the user, as usually cost and utility are the main concerns. These results suggest that a different, more user-focused approach should be used when designing and implementing the system.

5.6 Summary

The results from the survey found family sizes in this region similar to those found in other surveys, with on average, 1.1 child per house and 4 adults. Water collection is mainly done by women (71.8%). Technology awareness was mainly gained through word-of-mouth (59.7%) and door-to-door announcements from a representative involved with the technology implementation or operation (23.4%).

The median income for the entire sample is 4,500 Rupees per month. All villages' median incomes are less than the overall median, except for villages using BESU and PalT/Harbr which are significantly wealthier. The level of household income is related to the level of education of household members.

The survey revealed that though a water-option may be arsenic-free, it may not be a sustainable option due to lack of availability, like 'time' water (municipally-treated). Additionally, a water option that is widely believed to be arsenic-free, like deep tube wells, may in fact contain arsenic, suggesting the need for widespread arsenic testing. Treated water for the ten arsenic mitigation options were tested and showed arsenic concentrations of less than 50ppb in all cases. However only three arsenic mitigation technologies produced arsenic concentrations less than 10ppb: Tipot, PalT/Harbr and Dug Wells. This suggests that if the limit is lowered to the international standard (10ppb), many of the technologies included in this thesis would not be suitable for use. Analyses of raw water show that in many villages, a filter is essential to bring the arsenic concentration down to acceptable level (<50ppb). Failure to use a filter, for whatever reason, then puts the household at risk of arsenicosis.

The distribution of water sources and technologies used by each village is demonstrated. The majority of villagers within one community use the same filter or no filter at all, due to limited choices and the added costs of not participating in a subsidised project. This result validates classifying a village by the technology used in it (ie. a 'BESU' village). Assuming that the sampled population is representative of the entire Bengal region, it is estimated that between 59.8 and 167.9 million people are drinking arsenic-contaminated water.

Stakeholder (users) opinion identified the four most important issues that should be considered regarding arsenic mitigation technologies as cost, trust, distance to the filter (or home delivery) and understanding the effects of arsenic on health. Survey data allows a wide range of other issues to be ranked in importance from a user's perspective. The results presented in this chapter provide an overview of the survey and add context to the results chapters (6, 7 and 8), which deal with defining and utilization of indicators within the three capital domains.

6 Sociocultural Domain

This chapter presents the sustainability impacts of the ten arsenic mitigation technologies on the human/social capital domain. An explanation of the scoring of the sub-indicators is followed by a detailed discussion of the composite indicators which are: Trust-Confidence; Convenience; Awareness; Acceptability; and Compatibility. Finally, the total scores of the composite indicators are weighted and presented to give an overview of relative sociocultural scores for the technologies surveyed.

6.1 Scoring of Sub-Indicators

The five indicators identified in the sociocultural capital domain each comprise several sub-indicators. Most sub-indicators were identified through the PAM (Section 3.4) and a few were recognised while in the field during stakeholder interviews and observation. Each sub-indicator is initially assigned a score of 0 (poor), 1 (moderate/neutral), or 2 (good), and averages are calculated for the villages surveyed having the same technology (1-4 villages per technology). The raw scores are then weighted. The relative weights are based on the importance assigned to the various issues by respondents to interviews and questionnaires (Section 5.6).

6.2 Trust-Confidence Composite Indicator[1]

In the questionnaire, trust was identified as one of the four most important issues by users which included all the factors which can be characterised as either ‘trust’ or ‘confidence’. These were issues that caused the primary stakeholder to start, continue or terminate use of

[1] The approach is described in Etmannski and Darton, 2013.

the technology. According to Earle's principles of Trust, Confidence and Cooperation (Earle, 2006 and 2009), trust is social and relational, whereas confidence is instrumental and calculative. Trust is the willingness, in the expectation of specific outcomes, to make one vulnerable to another based on the assumption of similar intentions or values. Thus, trust is based on social relations and shared values. Confidence is the belief, based on experience or evidence that certain future events will occur as expected, and can be promoted by a variety of factors like regulations, procedures, contracts, record-keeping, experience, control or standards.

Therefore in Bengal, the level of user-confidence in a mitigation option will depend on the technology's design and whether it fulfils specific expectations. The user's degree of trust is based on his/her perception of a whole series of interactions with people associated with the mitigation technology (NGO, implementers, village leaders, operator/supplier). The power-balance between different stakeholders is unique to each relationship and can also affect the user's degree of trust in a system. For example, having the opportunity to influence change and make complaints about the operation, implementation and/or management of a system in a space without community judgement increases trust by enhancing accountability.

According to Earle, both trust and confidence, in a range of combinations, can lead to various forms of cooperation. This is explored in the analysis by quantifying both trust and confidence separately, then combining them in a single composite indicator for each of the ten technologies. The considerations underlying the choice of sub-indicators making up the separate trust and confidence indicators are as follows:

<u>Trust</u>

- *Method of engagement.* Trust in the organisers of a mitigation project is highest with full community participation. 0= No engagement with community/village, direct with only an individual/family; 1= Engaged with Panchayat (council of village elders). It is assumed that the Panchayat represents the people and has their best interest in mind; 2= Contacted a pre-existing (well-established) group/club within the community, that is run by the community itself.

- *Behaviour*[2] *of local leaders.* How local leaders interact with the technology influences the wider user community. 0= They do not use (demonstrate indifference or do not support the technology); 1= Sometimes use (irregularly); 2= Always use (supportive of technology).
- *Behaviour of operator/supplier.* Community-scale technologies have one or more operators; household-scale technologies are operated by the householder who is dependent on a supplier who organizes the purchase of the technology, sells or provides replaceable parts and collects and/or regenerates the waste. Trust in the operator or supplier influences attitudes to the technology. 0= Bad (not liked, thought to be a bad person, untrustworthy and/or lazy); village questions whether proper maintenance or operating procedures are being adhered to; 1= Neutral (mixed reviews of the person's good-standing within the village or people are generally neutral or have no opinion about the matter); 2= Good (considered to be a respectable/trustworthy person in the village; Most people trust them to do correct maintenance/operational procedures/sales etc).
- *Accountability of operator/supplier.* Greater accountability of key figures improves trust in their decisions and actions. 0= No ability for average villager to express concerns about the system neutrally; or no mechanism for change; 1= Some ability to ask questions and express concern but no systemic way to initiate change; 2= Villagers have a way to make complaints, give feedback and ask questions about every step in the system neutrally and there is a mechanism incorporated in the system allowing for accountability, change and correction.

[2] Behaviour refers to actions observed by the user, and interactions with the user.

Confidence

- *Durability.* Faults in the equipment undermine confidence in its efficacy.

  0= Breaks/malfunctions very easily or is very sensitive and easily disrupted;

  1= Malfunctions on occasion and is affected by moderate condition changes;

  2= Breaks down or malfunctions never or only very rarely.

- *External appearance of technology.* A clean, neat, professional set-up inspires confidence. 0= Unorganised, haphazard, dirty, rusty; 1= Moderately clean neat and professional; 2= Very clean, neat and professional.
- *Diarrhoea after ingestion of treated water*[3]. This symptom can undermine confidence. 0= Regularly; 1= Sometimes; 2= Never.
- *Transparency of financing / costing.* Confidence that costs are fair and reasonable is promoted by openness. 0= None at all; 1= Some/Limited; 2= All (total transparency accessible by any and all villagers if desired).
- *Proof of regular arsenic testing.* Confidence is enhanced by regular up-to-date certification of water quality and publication of results. 0= None, never; 1= Yes, sometimes; 2= Yes, regularly.
- *Presence of appropriate signage.* Relevant information about the technology implementation, in a language that can be understood, raises confidence.

  0= None; 1= Some signage with minor missing information; 2= All relevant information present in the local language.

[3] Some technologies remove iron, which can cause diarrhoea when users switch to this water source. Diarrhoea can also be caused by many other factors. Villagers tend to use the occurrence of diarrhoea as an indicator of "bad" water, so it is used as a negative indicator.

The scores and weighting factors were chosen so that the final maximum weighted score for Trust was 50% higher than that for confidence for several reasons. First, Earle's Trust-Confidence-Cooperation model specifies a direct interaction between trust and confidence, with trust dominating confidence (Earle, 2006). It appears that confidence is fragile and trust is robust, so that confidence is easily made and broken while trust takes longer to build and can withstand more stress. Once broken though, rebuilding trust may require more effort, making it considerably more important to foster and maintain. Second, since by definition trust is social and interpersonal, it is weighted more highly than confidence because of the high value placed on social relationships and interactions by rural Bengali people (Banerjee, 2008). The final scores in Table 6.2 are therefore related to a maximum possible score of 10.5, but they can be normalised on any scale, because they are relative. Tables 6.1 and 6.2 reveal aspects in which particular technology systems may be improved in order to promote trust and confidence and hence utilisation.

Technology	**Confidence (weighted maximum = 4.2)**												**Weighted Total /4.2**
	Durability		External Appearance of Tech		Diarrhoea after Ingestion of Treated Water		Transparency of Financing / Costing		Proof of Regular Arsenic Testing		Presence of Appropriate Signage		
	Coded	Weighting	Coded	Weighting	Coded	Weighting	Coded	Weighting	Coded	Weighting	Coded	Weighting	
	/2	1.00	/2	0.15	/2	0.15	/2	0.15	/2	0.50	/2	0.15	
Tipot	2	2.00	1	0.15	0	0.00	0	0.00	0	0.00	0	0.00	2.15
IITB	2	2.00	1	0.15	1	0.15	1	0.15	0	0.00	1	0.15	2.60
BESU	2	2.00	1.7	0.26	1	0.15	1	0.15	1.7	0.85	1	0.15	3.56
PalT/Harbr	2	2.00	2	0.30	2	0.30	0	0.00	0	0.00	1	0.15	2.75
AIIH&PH	0	0.00	1	0.15	1	0.15	0	0.00	0	0.00	1	0.15	0.45
CGCRI	1	1.00	1	0.15	1	0.15	0	0.00	0	0.00	1	0.15	1.45
Dug	1	1.00	1	0.15	1	0.15	1	0.15	0	0.00	1	0.15	1.60
Sono 45/25	0	0.00	1	0.15	1	0.15	0	0.00	0	0.00	0	0.00	0.30
Nirmal	0	0.00	1	0.15	1	0.15	1	0.15	0	0.00	0	0.00	0.45
DRDO	0	0.00	2	0.30	1	0.15	1	0.15	0	0.00	1	0.15	0.75

Table 6.1 Confidence sub-indicator scores.

Technology	Trust (weighted maximum =6.3)								Weighted Total /6.3	Trust-Confidence Combined Weighted Total /10.5
	Method of Engagement		Behaviour of Local Leaders		Behaviour of Operator / Supplier		Accountability of Operator / Supplier			
	Coded	Weighting	Coded	Weighting	Coded	Weighting	Coded	Weighting		
	/2	0.59	/2	1.19	/2	1.19	/2	0.18		
Tipot	1	0.59	0	0.00	0.5	0.60	0	0.00	1.19	**3.34**
IITB	1.3	0.77	2	2.38	2	2.38	1.3	0.23	5.76	**8.37**
BESU	1.7	1.01	1	1.19	2	2.38	1.7	0.31	4.89	**8.44**
PalT/Harbr	1	0.59	1.8	2.14	2	2.38	2	0.36	5.47	**8.22**
AIIH&PH	1	0.59	0	0.00	1	1.19	1	0.18	1.96	**2.41**
CGCRI	0	0.00	0	0.00	0.3	0.36	0	0.00	0.36	**1.81**
Dug	1	0.59	0.7	0.83	1	1.19	1	0.18	2.79	**4.39**
Sono 45/25	1	0.59	2	2.38	0	0.00	0	0.00	2.97	**3.27**
Nirmal	1	0.59	0.7	0.83	0	0.00	0	0.00	1.42	**1.87**
DRDO	1	0.59	2	2.38	0	0.00	0	0.00	2.97	**3.72**

Tables 6.2 Trust sub-indicator scores and Trust-Confidence Totals for mitigation options.

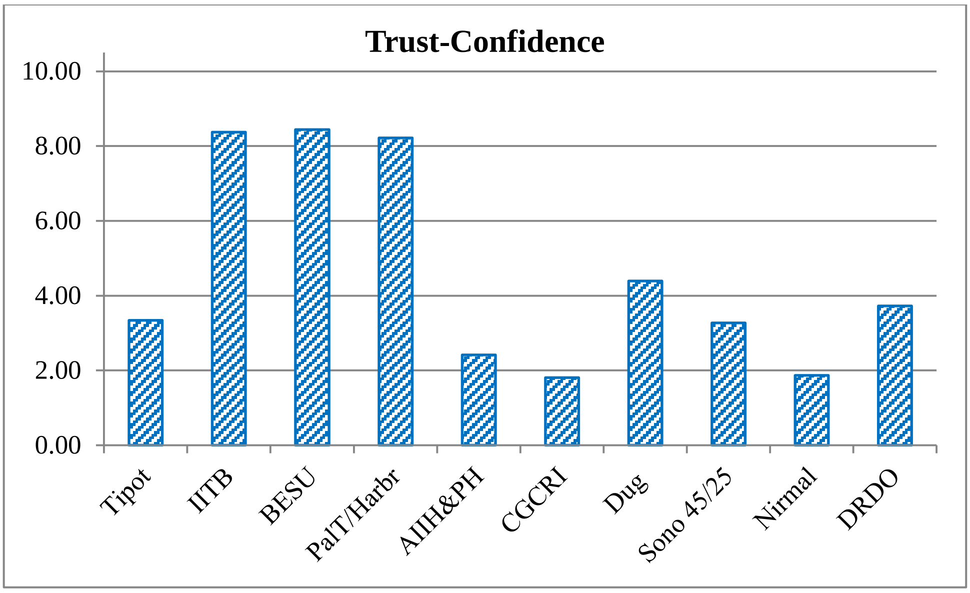

Figure 6.1 Total Trust-Confidence score found for each option.

The arsenic mitigation technologies developed by IITB, BESU and PalT/Harbr obtained the highest values of Trust-Confidence (Figure 6.1). Dug wells scored the fourth highest. These four arsenic mitigation options showed the highest levels of community participation, support by local leaders and professional behaviour by operators/suppliers. The DRDO, Tipot, Sono 45-25, and AIIH&PH scored in the mid-lower end in Trust-Confidence, with Nirmal and CGCRI scoring the lowest. All three household-scale technologies fell in the lowest range. Interestingly, the one technology that is implemented for-profit within communities is the CGCRI, which has the lowest Trust score. In comparison, the four top technologies identified here, have partnered with local NGOs and/or community groups ensuring that any profit made from the selling of treated water goes back into the mitigation project itself or another social project that will directly benefit the community. This suggests that there is probably also a strong connection with the economic capital domain, which is supported by the fact that the stakeholders identified ‘Cost’ as also being a very important issue. Conducting a triple-bottom-line analysis is needed to obtain a complete understanding of what affects the sustainability of arsenic mitigation options.

6.3 Convenience Composite Indicator

Consistent with the findings of Hoque et al. (2004), another key issue for primary stakeholders was the distance to the water source. Their research, like this study, found that users preferred piped water (home tap water). Shafiquzzaman et al. (2009) conducted a technical and social evaluation of arsenic mitigation technologies in rural Bangladesh and reported that 56% of respondents choose not to use an arsenic-free water supply because the source is located too far from their houses. This suggests that the distance to the water source (home delivery or home tap water) is important because it influences decisions regarding utilisation. Clearly the level of ‘convenience’ is an important factor.

The concept of convenience first appeared in academic literature relating to the design and marketing of products which offered ‘time-saving’ features (Copeland, 1923). Becker (1965) expanded on the concept of ‘time-saving’ by incorporated time into the classic economic choice model, recognising that time (like income and price) constrains choice. However unlike money, time is a limited and scarce resource because time cannot be expanded (Jacoby et al., 1976). Therefore, the term ‘time-saving’ actually means reallocating time across activities to achieve greater efficiency (Gross, 1987), and in this context means decreasing the amount of time used to complete activities related to arsenic mitigation technologies. Time-saving measures are important to Bengali households because working hours are limited by daylight, as most villages have no electricity, and because all household duties are very labour-intensive (cooking from scratch, washing clothes by hand).

Convenience is the value consumers place on goods and services with inherent time or effort-saving characteristics (Voli, 1998), and researchers agree that convenience has a major impact on consumer buying decisions (Berry et al., 2002). Brown et al. (1989) applied the concept of economic utility to analyse convenience (for the consumer) in terms of the four dimensions: time, place, possession and form. The most convenient product or service would be available continuously (time), everywhere (place), and would require no effort to acquire (possession) or use[4] (form). Figure 6.2 shows a list of water treatment options ranked in order of convenience.

LEAST CONVENIENT
Self-collection, treatment and maintenance
Centralised treatment and maintenance but self-collection
Centralised treatment, maintenance and delivery
Treated piped water in home (if always available)
MOST CONVENIENT

Figure 6.2 Ranking levels of convenience for water treatment options in rural India (based on the idea of Brown, 1989).

The four dimensions of Brown et al. (1989) help to clarify and categorise the issues related to convenience identified through the PAM. These issues can be

[4] The action of filling up water containers was not considered as an issue in this context as every technology requires the user to use a tap; making them equal in convenience in this regard.

represented by the following eight sub-indicators.

<u>Convenience</u>

- *Distance to As-free water*[5]. Travelling further to collect water increases the time spent for collection and thus decreases level of convenience. 0= self-collection far (>250m); 1= self-collection near (≤250m); 2= home access or delivery.
- *Accessibility of replaceable parts.* Convenience is greater when parts can be obtained easily and locally. 0= Out-of-village service/supply; 1= In-village but only one source (store); 2= In-village with multiple sources.
- *Duration of initial installation.* Long installation times cause frustration in users.[6] 0= >1 month; 1= between 1 month and 1 week; 2= ≤ 1 week.
- *Frequency with which technology is affected by power outage.* Villages suffer from unreliable electricity supply which prevents the use of any mitigation technology which relies on externally sourced electricity.[7] 0= >2 hrs/day; 1= ≤2 hrs/day; 2= not affected (0 hrs/day).
- *Daily period for which treated water is available.* Water available at any time is more convenient. 0= irregular hours; 1= peak hours (morning and evening); 2= all day.
- *Flow/filter rate of the technology.* Lower flow/filter rates mean longer waits to obtain treated water, causing more inconvenience. 0= ≥1 minute/litre;

  1= between 1 minute and 10 seconds per litre; 2= <10seconds/litre.
- *Conducting maintenance.* Centralised maintenance is more convenient than

[5] Khan and Yang (2013) explored households' in Bangladesh 'willingness-to-walk'. They found that most stakeholders believed that walking a range of 0–250 m and spending 10–30 min per trip was a reasonable distance and time for arsenic-free water collection.

[6] The stress, boredom, anxiety and annoyance often triggered by waiting influences consumers evaluation and satisfaction of a product or service (Taylor, 1994).

[7] Human-power (hand-pump) or solar-powered technologies are not affected by this inconvenience

self/household maintenance. Additionally, longer maintenance periods are less convenient so maintenance is less likely to be done (Kabir and Howard, 2007). 0= self-maintenance; 1= centralised maintenance ≥ once/week; 2= centralised maintenance < once/week.

- *Purchasing made easy.* A clear understanding of payment procedure enhances convenience. Typical uncertainties are: the tariff, who to pay, how and when to pay, what mode of payment is acceptable (cash, pre-paid, future payment options). 0= both unclear/non-standard pricing <u>and</u> unclear payment mechanism (knowing who to pay and when); 1= unclear/non-standard pricing <u>or</u> unclear payment mechanism; 2= clear, stable and competitive prices with prepayment, payment plan, and/or onsite payment available.

Convenience																	
Dimension:	Place				Time						Form				Possession		
Technology	**Distance to As-free water**		**Accessibility of replaceable parts**		**Duration of installation**		**Affected by power outage**		**Hours treatment available**		**Flow/filter rate of tech**		**Conducting maintenance**		**Purchasing made easy**		**Weighted Total (/12)**
	Coded	Weight	Coded	Weight	Coded	Weight	Coded	Weight	Coded	Weight	Coded	Weight	Coded	Weight	Coded	Weight	
	/2	1	/2	0.5	/2	0.5	/2	0.5	/2	0.5	/2	1	/2	1	/2	1	
Tipot	0.5	**0.5**	1	**0.5**	0	**0**	0	**0**	2	**1**	2	**2**	1	**1**	1	**1**	**6**
IITB	0.67	**0.67**	1	**0.5**	1	**0.5**	2	**1**	2	**1**	1	**1**	2	**2**	1.33	**1.33**	**8**
BESU	0.67	**0.67**	0	**0**	0	**0**	0.67	**0.34**	0.67	**0.34**	2	**2**	1	**1**	1.67	**1.67**	**6.02**
PalT/Harbr	0.25	**0.25**	0	**0**	1	**0.5**	1.25	**0.63**	1.25	**0.63**	2	**2**	1	**1**	1.75	**1.75**	**6.76**
AIIH&PH	0.67	**0.67**	0	**0**	1	**0.5**	2	**1**	1.33	**0.67**	1	**1**	1	**1**	1	**1**	**5.84**
CGCRI	1	**1**	0	**0**	2	**1**	1.33	**0.67**	1	**0.5**	1	**1**	1	**1**	2	**2**	**7.17**
Dug	0.67	**0.67**	1	**0.5**	1	**0.5**	2	**1**	2	**1**	2	**2**	2	**2**	2	**2**	**9.67**
Sono 45/25	1	**1**	0	**0**	2	**1**	2	**1**	1	**0.5**	0	**0**	0	**0**	2	**2**	**5.5**
Nirmal	1	**1**	0	**0**	2	**1**	2	**1**	1	**0.5**	0	**0**	0	**0**	0	**0**	**3.5**
DRDO	1	**1**	1	**0.5**	2	**1**	2	**1**	1	**0.5**	0	**0**	0	**0**	1	**1**	**5**

Table 6.3 Convenience sub-indicator results and totals for mitigation options.

The weighting of each Convenience sub-indicator was set at: 1 if the user encounters inconvenience that cannot be readily accommodated and 0.5 if the inconvenience is significant but can be accommodated to some extent.

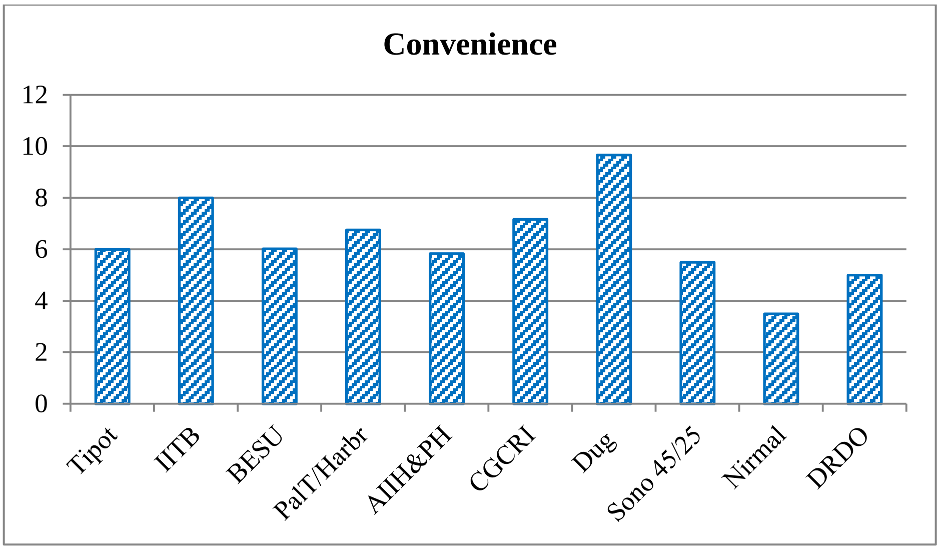

Figure 6.3 Total Convenience score found for each technology.

The mitigation option that scored highest in Convenience is the Dug well, followed by the IITB. Both these options use local components, are accessible all day and are very easy to maintain. The CGCRI scored the third highest and received full scores in the 'duration of installation' and 'purchase made easy' categories, perhaps related to the for-profit nature of the CGCRI projects. The other community-scale technologies fall in the mid-range, similarly scoring around six. The three household scale technologies prove to be somewhat less convenient for users.

6.4 Awareness Surrogate Indicator

Arsenic contamination of drinking water is a public health problem, and understanding this aspect is an essential prerequisite to a successful arsenic mitigation programme. The lack of coordination between public health authorities and drinking water supply professionals has further complicated the mitigation efforts in the Bengal Basin (Milton et al., 2012). This is discussed by Brouns et al. (2013) who found that many people in rural Bihar (a district of West Bengal, India) still do not know about arsenic and the need for mitigation. These authors comment that for any mitigation programme to work, overall improved awareness of the arsenic problem is necessary. This suggests that arsenic mitigation ought to be viewed as a service, which includes awareness campaigns, not just as the sale or implementation of a product. Similar examples of this equipment-plus-information model include distribution of mosquito nets in developing countries alongside malaria-awareness campaigns (Project Mosquito Net, 2014), and supplying free contraceptives together with family-planning support and HIV/AIDS awareness (UNFPA, 2012).

Results in Figure 6.4 show that more than 50% of people in the villages we surveyed state that they do not know whether their household tube well contains arsenic or not.

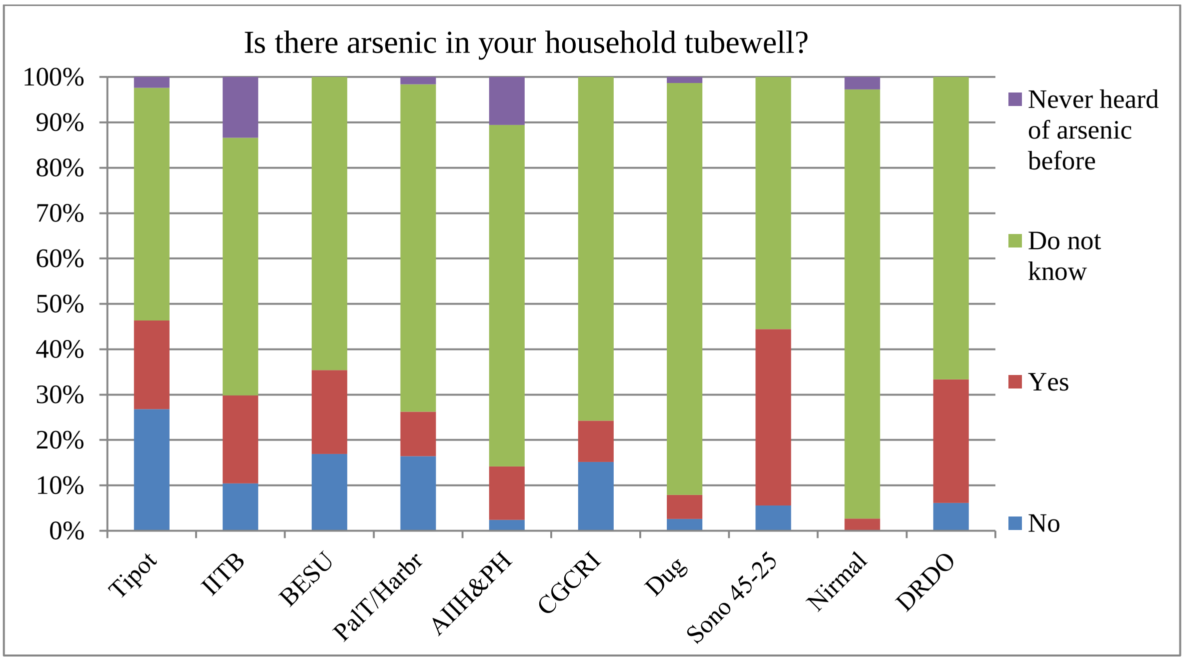

Figure 6.4. Average distribution of answers to the question ‘Is there arsenic in your household tubewell’ for villages using each technology.

The households that answered ‘yes’ or ‘no’ to the question whether arsenic was present in their tubewell were asked a supplementary question about how they could be certain. The answers to this supplementary question revealed that their belief about the purity of their water was often based on whether one or more family member was suffering or had suffered from arsenic-related ailments (commonly identified by black spots on the body). None of the respondents interviewed had had their household tube well tested.[8] Therefore beliefs on 'yes' or 'no' as shown in Figure 6.4 must be regarded largely as guesses.

It is sometimes thought that arsenicosis is contagious so any occurrence may be kept secret to avoid ostracism by family and/or village. Hanchett et al. (2002) reported that 41% of Bangla women surveyed thought that arsenicosis was a contagious disease. George et al. (2013) assessed awareness of the arsenic problem in Bangladeshi villages and demonstrated confusion regarding the health implications of chronic arsenic exposure. The majority of respondents incorrectly stated that cholera, diarrhoea, and vomiting could be caused by arsenic and nearly 70% of participants incorrectly stated that boiling could remove arsenic from drinking water, and that eating or sleeping with an arsenicosis patient could cause the transmission of the disease. Many other authors describe similar observations regarding lack of arsenic awareness (Aziz et al., 2006; Caldwell, 2003; Hanchett et al., 2002; Paul, 2004). An added complexity to the lack of general understanding and awareness of arsenicosis in Bengal is that there is similarity of some clinical symptoms of arsenicosis to leprosy, particularly disfigurement of skin. Leprosy, a familiar infectious illness in Bengal, carries significant negative social stigma. Our household survey contained no questions exploring the household's degree of knowledge surrounding the health effects of arsenic however the literature is clear that misconceptions are common. The survey revealed a desire by rural residents to know more about it, as households rated the issue 'understanding the physical effects of

[8] Melamed (2005) reviewed technologies with field measurement potential for monitoring arsenic and concluded that affordable and accurate measurement of arsenic in the field remained a technical challenge. It currently costs 2,500 Rupees to have one water sample tested for arsenic at a laboratory, not including the transportation costs. This is equivalent to 17 days income for the average household in our survey (income figures are given in Section 5.2). Most families have not had their tube wells tested due to the cost and logistical difficulties.

arsenic' as one of the four highest in importance relating to arsenic mitigation options (along with Trust, Distance and Cost) (Section 5.6).

The survey also did not ask whether users were aware of arsenic presence in waste created by mitigation options. However the survey does show that arsenic-rich waste is commonly treated in a way that demonstrates poor understanding of the dangers of this toxic material (Section 7.3.2).

Knowledge of whether arsenic is present in untreated household tube wells, understanding the health effects of arsenic, and community awareness surrounding arsenic presence in waste, are all necessary for sustainable implementation of any mitigation technology. Indicators could be created for these three issues, which together would represent the degree of awareness composite indicator. However since these values were not measured during the fieldwork, a surrogate indicator has been identified, and this takes the place of the awareness composite indicator in this analysis.

<u>Awareness Indicators</u>

- *Household's knowledge of arsenic concentration/presence in untreated water.*

  0= ≤50% of households have knowledge; 1= between 50% and 80% of households have knowledge; 2= ≥80% of households have knowledge.

- *Household's knowledge about physical effects of arsenic on human health.*

  0= ≤50% of households have knowledge; 1= between 50% and 80% of households have knowledge; 2= ≥80% of households have knowledge.

- *Household's knowledge of arsenic presence in waste.*

  0= ≤50% of households have knowledge; 1= between 50% and 80% of households have knowledge; 2= ≥80% of households have knowledge.

Surrogate Awareness Indicator

- *Declaration of community and/or school*[9] *arsenic-awareness campaigns.* A campaign including information on health effects of arsenic, the presence of arsenic in waste and thus the importance of proper disposal methods and widespread testing of household tube wells would improve the overall community awareness surrounding issues related to arsenic in drinking water.

  0= Community/school awareness session never held and no on-going campaign;

  1= Community/school awareness session held only one time with no tubewell testing; 2= Community/school awareness campaign on-going, including regular awareness sessions and household tubewell testing.

Awareness		
Technology	**Declaration of community and school arsenic-awareness campaign**	
	Coded	Weighting
	/2	1
Tipot	0	**0**
IITB	0.33	**0.33**
BESU	0.33	**0.33**
PalT/Harbr	0	**0**
AIIH&PH	0	**0**
CGCRI	0	**0**
Dug	0.66	**0.66**
Sono 45/25	0	**0**
Nirmal	0	**0**
DRDO	0	**0**

Table 6.4 Surrogate-indicator to measure degree of Awareness.

Most of the technologies have not incorporated the promotion of arsenic awareness into their system and therefore scored zero in the surrogate indicator. The

[9] Integrating drinking water safety in the schools' curriculum would be an important first step in achieving overall awareness (Brouns et al., 2013).

Dug well, IITB and BESU scored ‘1’ in only a few of the villages visited (not all) resulting in scores less than one. In these villages, a small amount of awareness-building had occurred, as households commented either that information about arsenic had been broadcast through a megaphone in the centre of the village (BESU) or that arsenic-related information had been conveyed through the field workers/operator (IITB and Dug).

There is a clear need for public awareness campaigns to be implemented alongside arsenic mitigation technologies. George et al. (2013) proved that awareness campaigns do work when they observed a dramatic reduction in urinary arsenic after promoting household-level arsenic awareness education together with provision of an arsenic testing service. This programme succeeded in persuading households to use arsenic-safe drinking water sources. It is also known from the work of Ahmad et al. (2005) that awareness of arsenic contamination bears a positive relationship to a household’s ‘willingness to pay’ for arsenic-removal. Increased knowledge and awareness should therefore make conditions more favourable for successful technology utilisation over time. Increasing public awareness might also change attitudes to arsenic-rich waste, and perhaps lead to the development of better disposal options, and adherence to stricter and safer disposal protocols.

6.5 Acceptability of Treated Water Composite Indicator

An important criterion in determining the sociocultural appropriateness of an arsenic mitigation option is the degree of acceptability of taste, smell and appearance of the treated water to the local users. Taste and odour can originate from natural inorganic and organic chemical contaminants and biological sources or processes, from contamination by synthetic chemicals, from corrosion or as a result of water treatment such as chlorination (WHO, 2004). Colour, cloudiness, particulate matter and visible organisms may also be noticed by users and may create concerns about the quality and acceptability of the drinking water supply. Hossain et al. (2013) performed a statistical analysis to find out if there is any association between taste and odour of filtered water and the decision to use an arsenic filter, and found that both significantly influenced the user's choice. Appearance of the treated water is also likely to affect the user's opinion of acceptability. Therefore taste, smell and appearance together make up the Acceptability of Treated Water composite indicator, with 0= poor, 1= neutral, 2= good, as the scoring (Table 6.5 and Figure 6.5).

Acceptability of Treated Water							
Technology	Taste		Appearance		Smell		Weighted Total (/6)
	Coded	Weighting	Coded	Weighting	Coded	Weighting	
	/2	1	/2	1	/2	1	
Tipot	1.25	**1.25**	1.5	**1.5**	1.5	**1.5**	**4.25**
IITB	2	**2**	2	**2**	2	**2**	**6**
BESU	2	**2**	2	**2**	2	**2**	**6**
PalT/Harbr	2	**2**	2	**2**	2	**2**	**6**
AIIH&PH	0	**0**	2	**2**	1	**1**	**3**
CGCRI	0.67	**0.67**	2	**2**	0.67	**0.67**	**3.34**
Dug	1	**1**	1	**1**	0.33	**0.33**	**2.33**
Sono 45/25	1	**1**	2	**2**	1	**1**	**4**
Nirmal	1.33	**1.33**	1.67	**1.67**	1.33	**1.33**	**4.33**
DRDO	1.5	**1.5**	1.5	**1.5**	2	**2**	**5**

Table 6.5 Sub-indicator results for the Acceptability of Treated Water composite indicator.

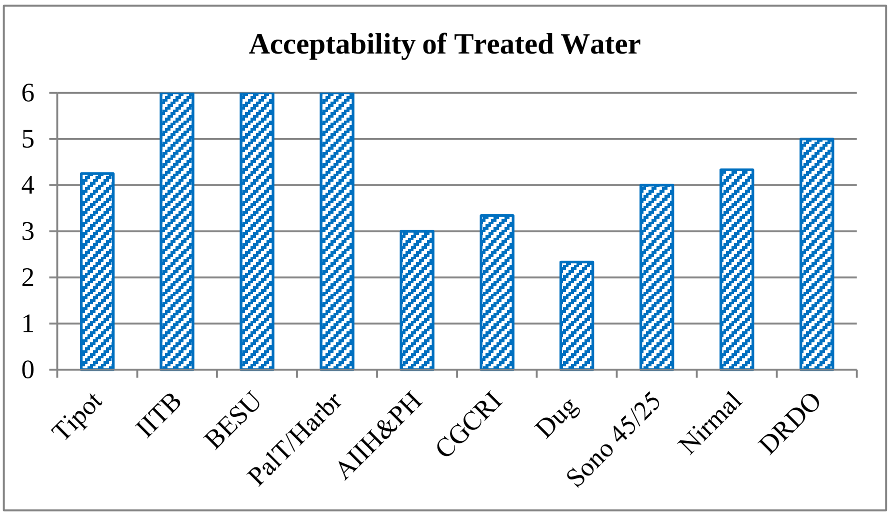

Figure 6.5 Total Acceptability score found for each technology.

The three mitigation options with perfect scores in the Acceptability of Treated Water indicator are IITB, BESU and PalT/Harbr. The DRDO, Nirmal, Tipot and Sono 45-25 (all three household-scale options) scored in the midrange, showing minor complaints in all three categories. CGCRI and AIIH&PH scored less well and Dug was let down by its score for smell. The three poorest scoring mitigation options in Acceptability are the only three which use chemical additives (either for chlorination, or oxidation purposes).

6.6 Compatibility Composite Indicator

Certain levels of technical expertise required to install operate or maintain an arsenic mitigation option may not match the level of expertise available within a rural community. There might also be a mismatch between levels of physical exertion required and that which is available (or willing). Requiring high levels of technical expertise or physical labour may then limit the utility of any particular technology. This has been the reason behind the failure of many arsenic mitigation projects in this region (Hossain et al., 2005; Alaerts and Khouri, 2004; Kabir and Howard, 2007), particularly when people who are already weakened by arsenic poisoning are required to conduct labour-intensive operation and maintenance activities (Johnston et al., 2010). The Compatibility composite indicator encapsulates these issues and is comprised of the six sub-indicators listed below (Table 6.6 and Figure 6.6):

<u>Compatibility</u>

0= maximum/great amount; 1= acceptable/moderate amounts; 2= ideal/minimal amount

- *Degree of technical expertise required to install technology.*
- *Degree of technical expertise required to operate technology.*
- *Degree of technical expertise required to conduct maintenance.*
- *Level of physical exertion required to install technology.*

- *Level of physical exertion required to operate technology.*
- *Level of physical exertion required to conduct maintenance.*

The scores for the sub-indicators were determined based on field observations and comments made by households during the informal interviews. There were no specific questions included in the survey which measured user opinion on these issues for each technology.

Compatibility													
Technology	**Degree of technical expertise required to install technology**		**Degree of technical expertise required to operate technology**		**Degree of technical expertise required to conduct maintenance**		**Level of physical exertion required to install technology**		**Level of physical exertion required to operate technology**		**Level of physical exertion required to conduct maintenance**		**Weighted Total (/12)**
	Coded	Weighting	Coded	Weighting	Coded	Weighting	Coded	Weighting	Coded	Weighting	Coded	Weighting	
	/2	1	/2	1	/2	1	/2	1	/2	1	/2	1	
Tipot	0	**0**	2	**2**	1	**1**	1	**1**	2	**2**	1	**1**	**7**
IITB	0	**0**	2	**2**	1	**1**	1	**1**	1	**1**	0	**0**	**5**
BESU	0	**0**	2	**2**	0	**0**	1	**1**	2	**2**	1	**1**	**6**
PalT/Harbr	0	**0**	2	**2**	1	**1**	1	**1**	2	**2**	1	**1**	**7**
AIIH&PH	0	**0**	2	**2**	0	**0**	1	**1**	1	**1**	0	**0**	**4**
CGCRI	0	**0**	2	**2**	0	**0**	1	**1**	2	**2**	0	**0**	**5**
Dug	1	**1**	2	**2**	1	**1**	0	**0**	1	**1**	2	**2**	**7**
Sono 45/25	2	**2**	2	**2**	2	**2**	2	**2**	1	**1**	1	**1**	**10**
Nirmal	2	**2**	2	**2**	0	**0**	2	**2**	1	**1**	1	**1**	**8**
DRDO	2	**2**	2	**2**	1	**1**	2	**2**	1	**1**	1	**1**	**9**

Table 6.6 Sub-indicator results for the Compatibility composite indicator.

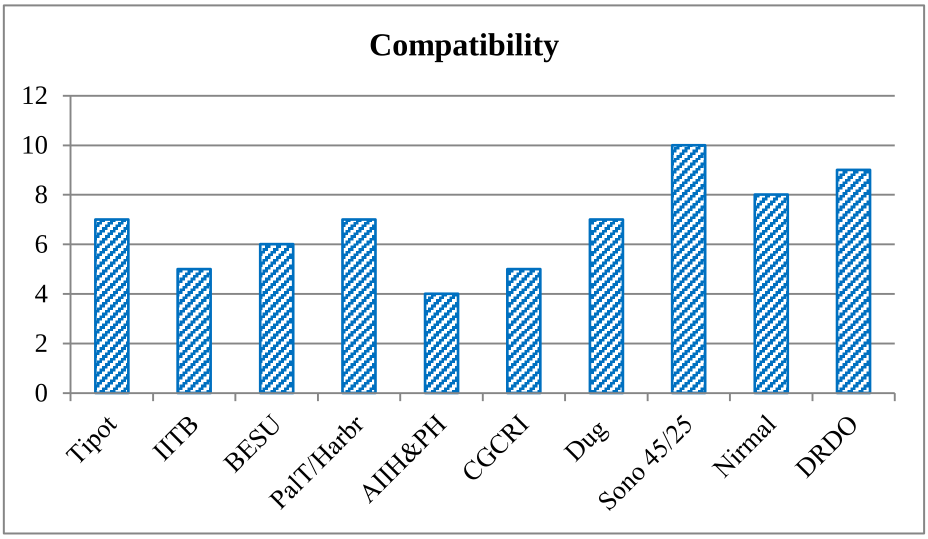

Figure 6.6 Total Compatibility score found for each technology.

The Sono 45-25, DRDO, and Nirmal, scored highest in the Compatibility indicator. They were all designed to be easy to use because they are at-home systems. The Dug wells, Tipot and PalT/Harbr ranked a little lower since they require moderate to high level expertise to install and maintain but are easy to use both technically and physically. BESU scores slightly less as it is requires significant technical expertise to conduct the maintenance (adsorbent regeneration). IITB requires more physical energy to conduct the monthly maintenance (cleaning of the nail beds), while the CGCRI requires both expertise and energy to conduct maintenance (washing the membrane) and AIIH&PH makes demands in all categories except it does not require any technical expertise in general operation.

6.7 Aggregation of Sociocultural Composite Indicators

The weighted totals of all the composite indicators are reported in Table 6.7 and are normalised so as to produce a total score with a possible maximum of 100. Trust-Confidence, Convenience and Awareness are weighted twice as much as Acceptability and Compatibility because they were identified by the users as the most important issues regarding the arsenic mitigation options (Table 6.7).

Sociocultural Composite Indicators											
Technology	Trust-Confidence		Convenience		Awareness		Acceptability		Compatibility		**Normal-ised Total (/100)**
	Weighted Score /10.5	Normal-ised /25	Weighted Score /12	Normal-ised /25	Weighted Score /2	Normal-ised /25	Weighted Score /6	Normal-ised /12.5	Weighted Score /12	Normal-ised /12.5	
Tipot	3.3	8.0	6.0	12.5	0.0	0.0	4.3	8.9	7.0	7.3	**36.6**
IITB	8.4	19.9	8.0	16.7	0.3	2.1	6.0	12.5	5.0	5.2	**56.4**
BESU	8.4	20.1	6.0	12.5	0.3	2.1	6.0	12.5	6.0	6.3	**53.4**
PalT/Harbr	8.2	19.6	6.8	14.1	0.0	0.0	6.0	12.5	7.0	7.3	**53.4**
AIIH&PH	2.4	5.7	5.8	12.2	0.0	0.0	3.0	6.3	4.0	4.2	**28.3**
CGCRI	1.8	4.3	7.2	14.9	0.0	0.0	3.3	7.0	5.0	5.2	**31.4**
Dug	4.4	10.5	9.7	20.1	0.7	4.1	2.3	4.9	7.0	7.3	**46.9**
Sono 45/25	3.3	7.8	5.5	11.5	0.0	0.0	4.0	8.3	10.0	10.4	**38.0**
Nirmal	1.9	4.5	3.5	7.3	0.0	0.0	4.3	9.0	8.0	8.3	**29.1**
DRDO	3.7	8.9	5.0	10.4	0.0	0.0	5.0	10.4	9.0	9.4	**39.1**

Table 6.7 Composite indicator results (weighted and normalised) for sociocultural capital.

Figure 6.7 is a bar graph of the total normalised sociocultural scores from Table 6.7. The graph highlights that even the poorest scored options (AIIH&PH and Nirmal) offer the user benefit in terms of arsenic removal but the better ranked options (IITB, BESU and PalT/Harbr) offer some examples of best practice that could be more widely adopted. However even these top ranked technologies can still be greatly improved in terms of sociocultural aspects, as they only score around 50% of the maximum score potential.

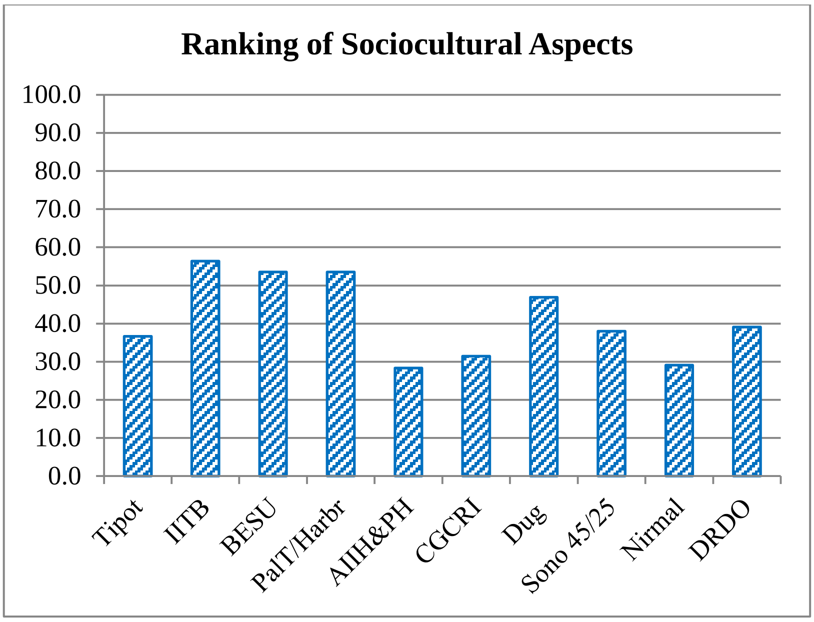

Figure 6.7 Total scores for sociocultural aspects for each mitigation option.

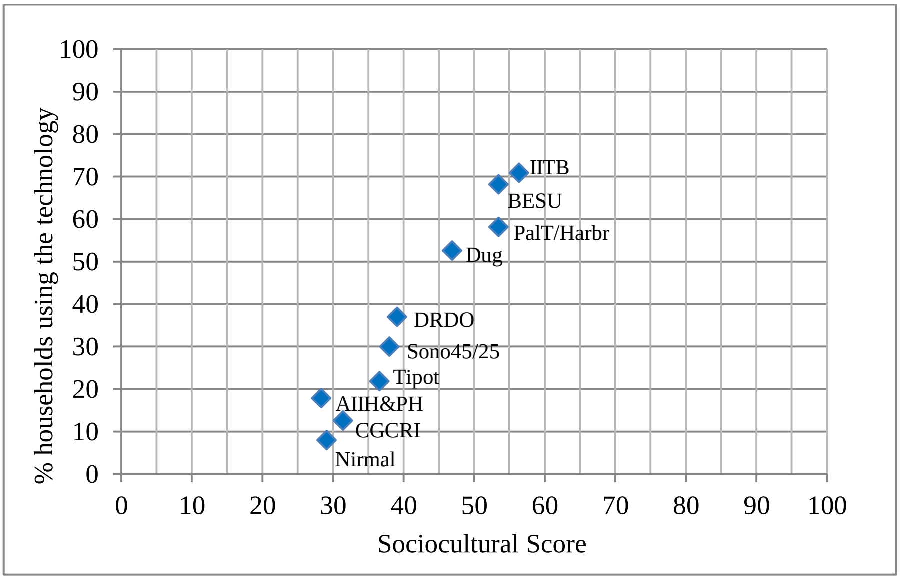

Figure 6.8 Utilisation of option in villages surveyed, related to total Sociocultural Score.

The scoring of sociocultural aspects has relied heavily on the household survey so it might be expected that the highest ranked mitigation options would prove popular with users. This expectation is tested in Figure 6.8. The percentage of households in villages using a particular technology is plotted against the total sociocultural score for that technology in those villages, normalised to a scale 0-100. As expected, there is a strong correlation between utilisation and sociocultural indicators. These data suggest that a technology with a sociocultural score of less than about 25% will prove wholly unattractive and potential users will prefer some other alternative. Above this threshold the utilisation increases linearly with sociocultural score. The technology with the highest score on this analysis (IITB, sociocultural score 56%) was utilised by 70% of the community.

6.8 Summary and Discussion

According to the household survey of user opinions, three of the four most important issues associated with arsenic mitigation technologies fall into the sociocultural domain: trust, distance to the filter (convenience) and understanding the effects of arsenic on health. The mitigation options that scored the highest in Trust-Confidence are IITB, BESU and PalT/Harbr. The top-ranked technologies in Convenience are Dug wells, IITB and CGCRI. At present, no mitigation option approaches implementation as a service that includes public awareness campaigns of arsenic-related issues, and therefore all technologies score very low in Awareness. Since these three composite indicators are of high importance to the users, they were weighted twice as much as the other two indicators that are also included within the sociocultural domain (Acceptability and Compatibility). IITB, BESU and PalT/Harbr produce the most acceptable treated water, and SONO 45-25, Nirmal and DRDO scored highest in compatibility.

Aggregation of the four composite indicators and one surrogate indicator resulted in a total sociocultural score for each technology. The options that scored highest overall are IITB, BESU and PalT/Harbr, however there is room for improvement in every mitigation option. A roughly linear relationship between total sociocultural scores and utilisation for each technology was demonstrated. This result shows that the technologies which are most highly used are those which meet user needs and expectations of the technologies to the greatest extent. Therefore, technology designers can improve the options by utilising the sociocultural indicators to 'script' (Section 3.2.1) for sustainable use.

The Trust-Confidence indicator specifically highlights the importance of community relationships and sociocultural norms in determining attitudes towards using arsenic mitigation options. This finding is in line with the findings of other authors who explored social factors related to the acceptance of piped-water supply schemes (Hoque et al., 2004), deep tube wells (Khan and Yang, 2013; Johnston et al., 2013), and switching to arsenic-safe shallow tube wells (Van Geen et al., 2002). Mosler et al. (2010) explored the degree to which personal, social and situational factors influenced the use of deep tube wells and found that in particular societal structure, family and neighbour behaviour were the crucial factors influencing user behaviour. Thus prioritising the ten aspects of Trust-Confidence into a design will likely improve take-up and continued use of a technology.

In addition, cooperation with the public health sector in implementing an arsenic-awareness campaign will also affect the uptake of mitigation technology. Hence, the incentive ought to be clear for mitigation projects to aim at high sociocultural scores.

7 Environmental Domain

This chapter introduces the concept of ‘product stewardship’ as an approach to exploring the environmental impacts generated during the three stages of life for each technology: ‘Design and Manufacture’, ‘Installation and Operation’ and ‘End of Life’. Indicators are generated for each stage, weighted and normalised to create a score for each technology in the environmental capital domain.

7.1 Product Stewardship

The concept of ‘stewardship’ is a way of framing relations between people and material resources or goods. Stewardship is often invoked to highlight the responsibilities of landowners or natural resource managers for maintaining environmental values of the resources they manage, so that those values may endure into the future. A key dimension of environmental stewardship generally is the linkage of property with some form of civic responsibility. The property may be in the land that produces the resources or in the goods that are produced from it. While discourse on stewardship has had a much stronger presence in relation to natural resource management, it is also important in the world of engineered products.

When products are sold, the traditional view has been that property and the responsibilities that go with it transfer to the consumer at the moment of purchase. In contrast, ‘product stewardship’ (PS) is the notion that all involved in the lifecycle of a product share responsibility for reducing its health and environmental impacts, with producers bearing primary financial responsibility. Ideas about PS developed from societal concern about responsible management of hazardous industrial waste, towards a broader focus on resource conservation and recycling which connects strongly with the Industrial Ecology (IE) school of thought (Huber, 2000). IE emphasises industrial material flows in terms of inputs, throughputs and outputs, each of which have different levels of environmental impact that can be measured through Life-Cycle Assessment (Graedel and Allenby, 2003), Ecological Foot-printing (Rees, 1992), or a similar context-relevant, ecosystem services accounting methodology. Extended Producer Responsibility (EPR), an extension of PS, is a policy approach in which the producer's responsibility for their product extends to the post-consumer management of that product and its waste (PSI, 2013).

In this analysis, a product stewardship approach is used when creating the sustainability indicators within the environmental-capital domain for arsenic mitigation technologies. Using the concepts of PS and EPR to frame the environmental domain is useful because it requires looking at the life cycle of these technologies with new perspective (Figure 3.1). Under an EPR scheme, waste generation during the operation phase and end-of-life phase are no longer just the problem of the user and the villages, but designers and implementers also share responsibility to ensure safe disposal. This is particularly important in Bengal where most arsenic-mitigation options produce large quantities of toxic waste. The indicators created in this chapter addresses this issue and together could aid in the creation of an Extended Producer Responsibility policy in Bengal.

7.2 Inputs – Design and Manufacture

The community scale technologies are constructed on-location using the components list in Table 7.1. The household-scale technologies are assembled in the factory and sold/distributed as a complete unit. All materials used in construction of the technologies are available for purchase within India, with the exception of the SONO 45-25 which is imported, already assembled, from a neighbouring country, Bangladesh. This means that the carbon footprint of material transportation is very minimal.

General Components	Materials
Pump	Submersible pumps; Steel hand pumps.
Filtration container	Steel boxes; Cylindrical stainless steel tanks; Plastic, ferro-cement, stainless steel buckets.
Connection tubes	PVC and galvanized steel tubing and joints; Soft plastic and rubber tubes; Hard plastic and steel spouts and taps.
Filtration media	Iron nails; Activated alumina; HAIX®; AdsorpAs®, Graded sand; Brick chips; Wood charcoal; Various oxidation and coagulation chemicals (sodium hypochlorite, aluminium sulphate); Ceramic membrane®; Fabric nets; Composite Iron Matrix®; Burned soil and rice husk candle.
Storage container	Various sized heavy-duty plastic tanks (Patton®, Polyxon®).
Building	Brick; Cement; Wall plaster and paint; Steel caging; Tin and hard-plastic ribbed roof sheeting; Metal gates; Wooden doors.

Table 7.1 Components used to construct the mitigation options.

The specific compositions of filtration media are largely unknown for most of the technologies since the media is often proprietary or trademarked and thus kept secret. It is therefore impossible to calculate a carbon footprint or conduct a cradle-to-grave ecological assessment on them. This research assumes that all the materials used in the creation of the filter media are sourced within India, as they are manufactured in India. The one environmental indicator chosen to represent the design and manufacture stage is:

- *Source of materials/product.* Distant sourcing of materials and components increases environmental impact through their carbon footprint, for example.

  0= Internationally sourced; 1= Nationally/regionally sourced; 2= Found locally (village).

Stage of product life:	Manufacture
Technology	**Source of material/ product** Coded (/2)
Tipot	1
IITB	1
BESU	1
PalT/Harbr	1
AIIH&PH	1
CGCRI	1
Dug	1
Sono 45/25	0
Nirmal	1
DRDO	1

Table 7.2 Coded results for the environmental indicator representing input into the mitigation options at the manufacture stage of life.

7.3 Throughputs – Operation and Maintenance

7.3.1 Energy

In India, non-renewable power plants constitute 87.55% of the installed electricity capacity, of which coal-fired plants account for 57% (EAI, 2012). Coal pollutes when it is mined, transported to the power plant, stored, and burned and thus has a very high negative environmental impact when used as an energy source. India currently suffers from a major shortage of electricity generation capacity, with a daily peak-hour power shortfall of 13% and transmission and distribution losses of 28.4% due to theft (IPS, 2012). In 2011, over 400 million Indian citizens had no access to electricity (EAI, 2012). For these reasons, arsenic mitigation options that rely on off-the-grid, renewable energy sources would prove more reliable and environmentally responsible. Renewable energy is typically defined as an energy resource that is replaced by a natural process at a rate that is equal to or faster than the rate at which that resource is being consumed (ie. solar, wind, tidal). Some of the mitigation options utilise hand pumps, which for this study will also be classified as renewable energy and therefore will be scored positively.[1]

- *Renewable energy used.* The utilization of non-renewable energy increases its environmental impact and therefore maximum use of renewable options is desirable. 0= None; 1= Partial or renewable on-grid; 2; All energy used is renewable and off-grid (including human-power).

Stage of product life:	Operation
Technology	**Renewable energy used** Coded (/2)
Tipot	0
IITB	2
BESU	0.67
PalT/Harbr	0.5
AIIH&PH	2
CGCRI	0
Dug	2
Sono 45/25	2
Nirmal	2
DRDO	2

Table 7.3 Coded results for the environmental indicator representing energy used during operation (throughput).

7.3.2 Creation of Toxic Waste

Whilst considerable progress has been achieved in terms of water treatment, the disposal of arsenic-rich waste (AsRW) generated from water treatment processes is a major issue that has received relatively little attention (Section 1.6). Arsenic removal technologies produce several different types of waste, including sludge/spent media and backwash slurries. Disposal of all hazardous waste requires effective management. Unfortunately, due to the absence of clear guidelines for the safe disposal of AsRW, it is often disposed of in an uncontrolled manner (Ashraf et al., 2003). This was also

[1] Note that in the Compatibility composite indicator (Section 6.6), the use of hand pumps scored negatively which is a good example of the existence of trade-offs present throughout the entire analysis.

witnessed during the field work. A common method for the disposal of sorbent filter media and regeneration waste is dumping it into brick-lined pits, which are prone to flooding and thus leaching into the surrounding environment. Incorporation of AsRW into construction materials is a solution commonly cited by various technology implementers and designers, but there is little evidence that it is routinely done. Little research has been conducted on the effects of inhalation of arsenic-rich dust which would be subsequently caused by erosion. Another management option for AsRW is to convert the arsenic into a stabilized or less mobile form and isolate it from the environment using a solidification and encapsulation process (Sullivan et al., 2010). Such methods may be suitable for treating waste generated by various arsenic removal technologies in West Bengal, however further research is needed to better understand the risks. In rural locations, options for disposal are very limited. It was most commonly observed that untreated arsenic-rich waste was dumped, buried or burned resulting in further point-source recontamination. Increasing public awareness about the arsenic problem might change attitudes towards the importance of correct disposal protocols of arsenic-rich waste, thereby reducing recontamination and the added risk of further exposure. The environmental indicators chosen to represent the operation and maintenance stage are:

- *Number of disposal locations for backwash/sludge.* Higher numbers increase the geographical spread of possible point-source recontamination of arsenic.

  0= >1 per village; 1= 1 per village; 2= A centralised location for several villages (or none required).
- *Physical location of disposal for backwash/sludge.* The degree of public access to the location and choice of land versus water disposal will also affect the degree of recontamination of arsenic.

0= A totally public space with open access that is widely used and/or disposal into a dynamic location (typically water: pond, river, aquifer; air: disposal by burning) or alternatively, non-transparency of disposal details; 1= A limited-access location that is less commonly used thus minimising contact with the general public and disposal into a static-site like a lined pit with no access to groundwater or surface water sources; 2= A controlled-access static-site that is not open to the public or easily accessible; or alternatively, no disposal is needed.

- *Method of disposal of backwash/sludge.* The species of arsenic will affect the degree of mobility within the environment and thus likelihood of recontamination. Therefore the arsenic-rich waste should be chemically treated to reduce this possibility. 0= No control of arsenic speciation, or disposal 'as-is'; 1= Arsenic is chemically converted to a less mobile state; 2= Disposal of arsenic in a professional manner so that there is no or extremely limited possibility of recontamination on the scale of 50 years; or alternatively, no disposal is needed.
- *Transport of waste.* Spillage is less likely to occur if the number of movements of waste is restricted, and when it is handled by trained operators and not untrained members of the public. 0= Users/operators are meant to transport waste to the disposal location by their own means; 1= Users/operators transport waste to a central location and the supplier collects the waste from the central location and transports it to the disposal site; 2= The supplier comes to collect the waste from every individual mitigation location and transports it to the disposal site, or no waste created.
- *Third party verification of waste disposal method.* Self-regulation does not significantly reduce pollution (Morgenstern and Pizer, 2007) therefore disposal methods that have been approved by a third party will have fewer negative environmental impacts.

0= No verification; 1= Self-verification completed; 2= All aspects of waste production, transport, and disposal have been verified by a third party to avoid all harm to people and the environment over the system's life cycle (50 years).

Stage of product life:	Operation and Mainanence							
Technology	**Number of disposal locations - Backwash**	**Location of waste disposal - Backwash**	**Method of Disposal - Backwash**	**Number of disposal locations - Sludge**	**Location of waste disposal - Sludge**	**Method of Disposal - Sludge**	**Transport of waste**	**Third party verification of waste disposal method**
	Coded (/2)	Coded (/2)	Coded (/2)	Coded (/2)	Coded (/2)	Coded (/2)	Coded (/2)	Coded (/2)
Tipot	2	2	2	2	2	2	2	1
IITB	2	2	2	1	0	0	0	1
BESU	1	1	0	2	1	1	0.3	1
PalT/Harbr	1	0	0	1	0	1	0	1
AIIH&PH	1	1	0	1	1	0	0	0
CGCRI	1	0	0	1	1	0	0.3	1
Dug	2	2	2	2	2	2	2	1
Sono 45/25	0	0	0	0	0	1	0	1
Nirmal	0	0	0	0	0	1	0	1
DRDO	0	0	0	0	0	1	0	1

Table 7.4 Coded results for the environmental indicator involving toxic waste during the operation and maintenance stage of life.

There was sometimes a difference between what manufacturers/implementer claimed to be the procedure for waste management (in literature and/or interview) compared to what was witnessed during the field work. The scorings in Table 7.4 are based on what was witnessed. For example, according to the NGO in charge of the DRDO technology, the arsenic-saturated balls are collected by the NGO and safely disposed of by converting the waste into bricks. However in actuality, villagers were told to burn or bury the ball. One villager hung the balls in his tree thinking it was safer up there than buried in the ground (Photos 7.1 and 7.2). Several trips to the brick factory were planned with the help of the NGO involved with the implementation of the DRDO, however a different excuse was given for cancelling at the last minute each time. The final reason given was that the bricks are not made during monsoon season (the period in which the team was present). Therefore disposal in this manner was not be verified by the field team.

Photo 7.1 The adsorbent of the DRDO is the ball inside the net.

Photo 7.2 Arsenic-saturated balls placed up a tree by the user to prevent any further contamination.

7.4 Outputs - End of Life

In India, municipal solid waste (MSW) management and resources related to sanitation are all the responsibility of local (city/village) government. However it is reported that none of the municipal authorities have been very effective in managing these areas, as widespread unregulated dumping of waste has become a serious problem across the country (Hazra and Goel, 2009; Clancy et al., 2013). The collection, transportation and disposal of MSW lacks appropriate infrastructure and maintenance and what does exist cannot keep up with India’s growing population (Gupta et al., 1998). Even in large developed cities like Kolkata, the capital of West Bengal, the city’s waste is not sorted, treated or disposed of at an engineered landfill. In 2009, it was reported that Kolkata’s MSW was simply dumped on land just outside the city (in Dhapa) after collection (Hazra and Goel, 2009). In rural regions, there is often no municipal collection or regulated disposal of MSW so households are responsible for disposal themselves. This explains why piles of rubbish were witnessed during the fieldwork, in ditches and fields, in every village visited. Disposal of arsenic mitigation equipment is a particular problem, as very little is collected by manufacturers or disposed of properly after the installation expires or breaks. For example, 1900 arsenic removal plants were installed in West Bengal starting in 1998. In 1999 a two year independent study evaluated 577 installations and found that 145 (25.1%) were already defunct and had been improperly disposed of (Hossain et al., 2005). Therefore, it is better to use technologies that have a longer lifespan because they produce less defunct equipment for disposal. In addition, an enforced extended producer responsibility policy should require manufacturers/suppliers to collect the systems for recycling at the end-of-life to reduce municipal waste creation in villages. The environmental indicators chosen to represent the end-of-life stage are:

- *Lifespan.* The longer the lifespan of the technology, the fewer times it needs to be replaced, decreasing the quantity of waste generated.

  0= <5 years; 1= 5-10 years; 2= >10 years.
- *Reuse and Recycling.* Incorporating reuse and recycling into the design of the technology will reduce the amount of waste created.

  0= None; 1= Some parts are reusable/recyclable; 2= All non-toxic components are reusable/recyclable.
- *Provision for end-of-life collection*. Creation of a plan for collection of defunct or expired technology which enables all recyclable and reusable parts to be acquired and decreases the amount of waste dumped.

  0= There is no provision for collection; 1= Provision for collection has been planned but never implemented. 2= Provision for collection has been planned and implemented successfully.

Stage of product life:	End of life		
Technology	**Lifespan**	**Reuse and recycling**	**Provision for end-of-life collection**
	Coded (/2)	Coded (/2)	Coded (/2)
Tipot	2	0	0
IITB	1	0	0
BESU	2	0	0
PalT/Harbr	1	0	0
AIIH&PH	1	0	0
CGCRI	1	0	0
Dug	1	0	0
Sono 45/25	0	0	0
Nirmal	0	0	0
DRDO	0	0	0

Table 7.5 Coded results for environmental indicators representing the end-of-life stage.

In cases like the dug wells or Tipot, where there is no above-ground technology, the ‘reuse and recycling’ and ‘provision for end-of-life collection’ indicators still apply as in both cases there are materials that could be salvaged at the end-of-life. With failed dug wells specifically, the sites should also undergo a reclamation process in which the wells are filled in so as to avoid a safety hazard.

7.5 All Environmental Indicators Combined

All the environmental indicators have been given a weighting of one except the three indicators involving the disposal of arsenic-rich sludge which were weighted as two. Sludge contains arsenic in significantly higher concentrations and quantities than the arsenic-ridden backwash (Sullivan et al., 2010; Clancy et al., 2013) and thus is more of an environmental concern, justifying the double weighting. All the indicators for the different stages of product life have been added together to create a total score for the environmental capital domain (Table 7.6).

Results from the total scores show that the Tipot and dug wells are significantly more environmentally responsible as neither produces arsenic-rich waste (Figure 7.1). BESU scores the highest out of all the technologies that actually produce arsenic-ridden waste. BESU gains points by having a central disposal centre used by technologies in the region. It lost points because during the field work, it was observed that untreated backwash was dumped in the field and ponds adjacent to the technologies, not in the controlled manner which is described in literature. If BESU practised the waste disposal procedure it claims to follow it would have scored 65 overall (rather than 46.8), which is significantly higher than any other arsenic-removal technology. IITB does not require any backwashing so it scored high in the backwash indicators, increasing its total score. The other mitigation options all score around 30% or less.

Stage of product life:	Manufacture	Operation and maintenance	End of life	**Total Score (/100)**
Technology	Total /2	Total /24	Total /6	
Tipot	1	21	2	**75.0**
IITB	1	11	1	**40.6**
BESU	1	11.97	2	**46.8**
PalT/Harbr	1	6.5	1	**26.6**
AIIH&PH	1	8	1	**31.3**
CGCRI	1	6.3	1	**25.9**
Dug	1	23	1	**78.1**
Sono 45/25	0	5	0	**15.6**
Nirmal	1	5	0	**18.8**
DRDO	1	5	0	**18.8**

Table 7.6 Total scores for indicators within difference stages of life, normalised out of 100.

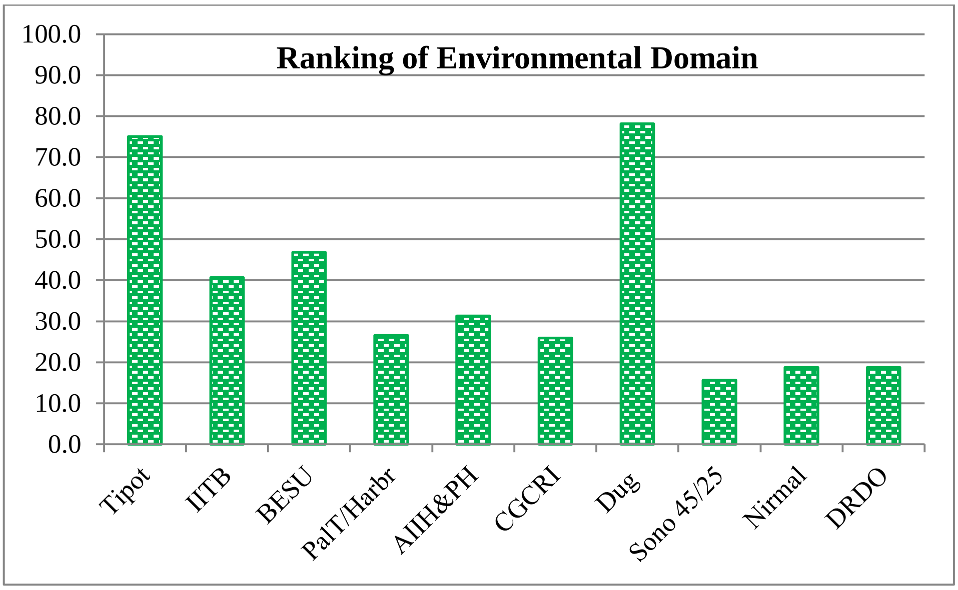

Figure 7.1 Total scores for environmental capital across all mitigation options.

7.6 Discussion

There were mixed results from the questionnaire regarding importance of environmental issues (Section 5.6). Users classified ‘environmentally friendly design’ as important (high on the scale) yet ranked ‘amount of municipal waste generated’ low on the scale of importance. As discussed previously (Section 6.4) awareness campaigns might influence users’ behaviours towards arsenic-rich waste and municipal solid waste which could influence product stewardship and help pressure manufacturers and suppliers to adhere to extended producer responsibility protocols.

This chapter highlights several issues within the product life cycle that fall in the environmental domain. Firstly, it was shown that India faces regular shortages and disruptions in supply of electricity. This causes one to rethink using on-grid power in the design of a mitigation option. Several issues related to arsenic-rich waste production and municipal waste production were highlighted and shown to be largely unaddressed by most of the mitigation options. Tipot and Dug wells scored highly overall because they are arsenic-avoidance options and do not produce AsRW. Based on the literature BESU has a good waste disposal methodology, it would also score very high (65) however practices witnessed in the field prove contrary to these assertions resulting in a significantly lower score (47). Despite this contradiction, it still proves to score the highest among all of the arsenic-removal options. IITB also scored relatively high. The DRDO also claimed to have a good disposal methodology however practices witnessed in the field were not in accordance with this methodology. This underlines the need for all parts of a mitigation project to be properly designed for sustainability and for supervision to ensure that prescribed best-practices are followed.

An important question suggested in this chapter is how to drive environmental improvement when it is not a high priority for users (as demonstrated in the survey). Since self-regulation or voluntary programmes do not significantly reduce pollution (Morgenstern and Pizer, 2007; Gamper-Rabindran et al., 2013) the involvement of third party verification has been added to the list of indicators. There is clearly a strong need for institutional intervention and cooperation (government, local authority, NGOs) to regulate the arsenic-mitigation sector. First, the creation and enforcement of product stewardship/extended producer responsibility policies could better control the material flow throughout a product's life and reduce environmental impacts. Second, creation of a separate and parallel waste collection and/or management system could prevent further widespread point source recontaminations and thus reduce potential future exposure. Finally, implementation of an arsenic awareness campaign would help influence the attitudes and behaviours of users both to encourage utilization of the technologies and also in promoting safe waste disposal practices. It is clear that the governments of India and Bangladesh need to increase their involvement in this industry through regulation, and could start by using the indicators defined in this chapter in an EPR scheme.

8 Economic Domain

This chapter examines the costs in Rupees (Rupee:USA exchange rate of 60:1) associated with each technology and issues related to those expenses. A viable economic model is presented as an alternative to what is being practised in the field, taking account for impacts examined in Chapters 6 and 7. A set of indicators is presented and discussed which together provide a total score for the economic domain.

8.1 Capital Costs

Table 8.1 shows the price of purchase and installation for each technology as found in literature or through interviews with designers and/or implementers.

Technologies	# of units	Cost of Purchase and Installation (per village)	Initial Subsidy (village pays difference)	Life span (yrs)	Total Capital Cost (for 10 yrs)
Tipot	1	420,000	420,000	10	420,000
IITB	1	80,000	80,000	10	80,000
BESU	1	200,000	200,000	10	200,000
PalT/Harbr	1	300,000	300,000	10	300,000
AIIH&PH	1	105,000	105,000	10	105,000
CGCRI	1	350,000	350,000	10	350,000
Dug	5	210,000	210,000	10	210,000
Sono 45/25	100	250,000	240,000	2	1,240,000
Nirmal	100	80,000	77,500	2	397,500
DRDO	100	200,000	190,000	5	390,000

Table 8.1 Capital costs of all technologies based on one village of 100 households and ten years of operation.

The cheapest community-scale technology to purchase and install is the dug well ($700/unit) however as it only caters for 20 households (on average), to service an entire village of 100 households requires five wells, and thus the total multiplied by five. For the same reason, the purchasing costs of the household-scale technologies were multiplied by 100. Most of the initial capital costs are paid for through NGO donations and/or government funding, with small amounts paid for by users in the case of the household-scale technologies. Since the household-scale technologies have an expected lifetime of less than ten years, replacement is required. As no further subsidy is expected, the replacement cost is the full price of the technology, which significantly increases the total cost for the household-scale technologies over ten years. Considering these high costs and the variability of both NGO and government funds, it is not realistic to assume that replacements for household-scale or community-scale options will be paid for in the future.

8.2 Recurring Costs and Income

Table 8.2 presents costs and income related to each arsenic mitigation option.

Technologies	# of units	Operating Expenses (Fixed)				Income			Net Income (/village /year)
		Electricity [-]	**Wage of operator [-]**	**Replaceable materials [-]**	**Total [-]**	**Utilisation (%)**	**Tariff charged (for 20L/day) [+]**	**Total (Tariff*Util) [+]**	
Tipot	1	3,900	0	120	4,020	22	0	0	**-4,020**
IITB	1	0	0	1,200	1,200	71	0	0	**-1,200**
BESU	1	6,000	13,800	10,000	29,800	68	48,000	32,736	**2,936**
PalT/Harbr	1	11,400	11,350	10,500	33,250	58	60,000	34,920	**1,670**
AIIH&PH	1	0	0	900	900	18	12,000	2,148	**1,248**
CGCRI	1	12,000	0	120	12,120	13	120,000	15,120	**3,000**
Dug	5	0	0	900	900	53	0	0	**-900**
Sono 45/25	100	0	0	0	0	30	0	0	**0**
Nirmal	100	0	0	20,000	20,000	8	0	0	**-20,000**
DRDO	100	0	0	20,000	20,000	37	0	0	**-20,000**

Table 8.2 Recurring costs and income for all options, per village per year in Rupees.

8.2.1 Wages

All mitigation options require an operator yet only two systems (BESU and PalT/Harbr) have included provision of payment for their time and efforts. The operators who are unpaid are potentially losing income (opportunity cost) by spending time working for free instead of working for money. Making no wage means less incentive to do the job properly, efficiently or even regularly. The wages that are being paid are only 30-33% of the median household income (4500 Rupees/mnth; $75/mnth) (Section 5.2). These particular technologies are located in villages with the highest local median incomes in the sample, with the operators of BESU being paid 19% of the local median monthly wage for halftime hours, and PalT/Harbr operators being paid13.5% of the local median income for fulltime hours. Sustainability requires that workers receive recognition through wage or some profit-share arrangement, otherwise the system is unstable.

The household-scale technologies are operated by someone from within the home so an operator is not paid. However the prolonged use of the Nirmal and DRDO models relies upon the adsorbent being replaced/regenerated, for which a third party is responsible. The successful long-term use of these options is thus dependent on someone providing maintenance support reliably, which was not observed to happen in any of the households visited. The users of the Nirmal were not aware of who they should contact to get the adsorbent regenerated. It was believed that person had moved away and nobody else had been trained as a replacement. The users of the DRDO claimed that the supplier of the adsorbent replacement (one local man in the community) inflated prices depending on his personal relationship with the buyer. He apparently received no salary, only profiting from the products sold, thereby creating incentive for price inflation. Some users of the DRDO were then forced either to pay higher prices or choose to abandon use of the system, which is what many families have done. These examples highlight the importance of project management and supervision (even if informal) to ensure quality control, to provide training and ensure ethical practice of workers.

8.2.2 Ownership and Profit

Operators of the AIIH&PH and CGCRI options were granted ownership over the technology and encouraged to use it as an entrepreneurial venture, so that any profits made were theirs to keep. The problem witnessed (while conducting field surveys) regarding this economic model, is that villagers resent the fact that any one individual might profit from selling them water, a necessity for survival. In these communities many individuals were critical of those profiting from sale of water and spoke openly about rejecting the use of these systems for this reason (Sections 2.1.5 and 2.1.6). In contrast, the PalT/Harbr systems generate a large profit which is promoted to the community as offering reinvestment through social programmes. This type of scheme did not cause such resentment among villagers. Also, PalT/Harbr systems were installed on the land of a municipal government office and a hospital, not on private homeowner's land, which added legitimacy to the venture.

8.2.3 Consumables

The costs of replaceable materials for BESU and PalT/Harbr are high because the adsorption media require replacement or regeneration at a cost of 10 000 Rupees per year (BESU) or 42 000 Rupees every two years (PalT/Harbr). The AIIH&PH requires chemicals to be replaced weekly and dug wells require chemicals to be added monthly (depending on weather). The Nirmal requires regeneration of media (like BESU) and DRDO replacement of media, both of which cost 200 Rupees per year. All the other options should only require minimal (nuts and bolts) level of maintenance with the SONO 45-25 not requiring any.

8.2.4 Tariff and Associated Issues

As there is no monthly tariff charged for treated water from the Tipot or IITB options, all monthly costs are paid by the operator. In the case of the Tipot, the monthly costs were originally paid through a five-year grant given to a local NGO. When the funding stopped the operator went door-to-door to the users to ask for contributions to help cover the monthly costs but as they had no means by which to contact the NGO to confirm the operator's story, they refused to contribute. The NGO in charge of the dug wells pays all costs, providing water for free to everyone. Having NGOs pay recurring costs is not economically viable in the long-term, as it is uncertain for how long the subsidy will be provided. Consumers were found to not understand the time-limited nature of financial support for NGO water schemes. During field work, those whose free-water schemes had come to an end displayed resentment or lack of understanding that money from rich donors was no longer available, and thus refused to pay.

Ahmad et al. (2005) found significant resistance to pay for arsenic-treated water and commented that this might reflect the long latency period of arsenicosis and the limited availability of information about the levels and dangers of arsenic contamination. This finding implies that more costly arsenic mitigation options may find little acceptance amongst users. Therefore increased knowledge and awareness might enhance the acceptability of arsenic mitigation options and make conditions more favourable for successful implementation. Khan and Yang recently surveyed households in rural Bangladesh and found that 56% of villagers believe that water should not be provided free of cost, while 44% of households believe that state should provide water free of cost because access to water is a basic human right (Khan and Yang, 2013). Therefore it is likely that there is still strong resistance to the idea of paying across all of Bengal.

In the case of the household-scale options, the users themselves are meant to pay any recurring costs however the majority stopped using the technology when any replacement part required purchasing. The users of the PalT/Harbr and CGCRI are spending 1.1% and 3.3% of their median income on treated water and AIIH&PH and BESU users are spending 0.2-0.3%. Chamberlain et al. surveyed households in Cambodia and found that villagers were willing to pay between 1.5% and 2.0% of their monthly household income on arsenic-treated water (Chamberlain et al., 2014). In America, the average household spends $51 on water utilities each month (Leak Bird, 2009) which equates, on average, to 1.2% of their monthly income[1] (Noss, 2013). In the United Kingdom, a charge of 2% income spent on water is seen as threshold indicating hardship (UNDP, 2006). During the field work, there were many complaints that the monthly tariff charged for treated water was too high (even in the cases of AIIH&PH and BESU). Therefore financial provision should be made for the poorest households in every community, to ensure they are not priced out of the market.

Roy et al. (2008) determined that reducing arsenic concentration in a family's drinking water incurs a saving of R297 per month by reducing sick-days and avoiding medical bills. This benefit more than covers the estimated monthly tariff shown in Table 8.2 and in the suggested scheme described in Section 8.3.2 (including delivery). The surplus results in a slight increase in disposable income for every family. As it is estimated that around 100 million people are affected by arsenic contamination in Bengal, the savings proposed by Roy et al. would add approximately 57 billion Rupees to potential spending in the region[2] (~$950 million). It is therefore in the best economic interest of both the household and government to reduce arsenic in drinking water.

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[1] Median American household income in 2012 was $51,324 (Nos, 2013).

[2] R297 Savings/month/family; 100,000,000 people with 5 people/family = 20,000,000 families
Arsenic-free water estimated to cost R60/month/family (Section 8.3.2); Net savings per family per month = R297 – R60 = R237; R237*12mnths*20,000,000 families = Total Net Savings of R56. 9 billion/yr.

8.2.5 Other Recurring Costs

The list of recurring costs in Table 8.2 does not include several other expenses that would feature in a more sustainable scheme. For example, regular laboratory testing to ensure the removal of arsenic from treated water would improve confidence in the system and affect utilization (Section 6.2), but it is not being done regularly at present. Options for delivery (door-to-door), a feature that would make the treated water more convenient for the users (Section 6.3) are also not offered. Additionally, there are no financial provisions made for disposal costs of toxic arsenic-ridden waste created during operation or any municipal waste created at the end of the technology's life. This waste commonly dumped in public spaces presenting a potential future hazard (Section 7.4).

8.3 A Viable Economic Model for Community-Scale Systems

Community-scale systems are more economically viable and environmentally responsible because they have lower replacement costs and produce less waste than household-scale technologies. Similarly, Khan and Yang (2013) concluded that community based systems allow for better water management, provides wider safe water coverage and also reduces the risk of localized contamination of the aquifer. A viable economic model for a community-scale system is described below, taking account of impacts outlined in previous chapters.

8.3.1 Modelled Capital Costs

All initial capital costs are to be paid for by the government or donated by an NGO. Capital costs include the price of the purchase and installation of the system and an initial gift (or loan) of R10,000 ($167) as start-up working capital. In addition, all lifetime costs related to toxic waste disposal are to be considered an additional capital cost and to be paid for by the government (as it is in the country's best interest for proper disposal). Proper control of waste is important for the wider community and future generations. This will require the creation of a toxic waste collection and disposal industry. As required by extended product responsibility protocols, it will be the responsibility of manufacture and suppliers to organise and manage a contract for regular collection and disposal of toxic waste.

The lifespan of any community-scale technology is largely uncertain, however it can be anticipated that every technology will require upgrading and in the worst case, replacement after approximately ten years. With this in mind, users will be charged a yearly fee which will help pay for these expenses when required. This fee is considered 'future capital' and is accumulated in a fund which provides for contingencies and for system replacement at end-of-life. The fee is set at R180 per year for each household (R15/mnth) and can be considered a type of membership or rental fee, allowing use of the facility. As shown in Table 8.3 the reserve accumulated in ten years of operation is R176,600. Reference back to Table 8.1 shows that this sum will purchase a new installation of some but not all the technologies included in this study. It may however not be necessary to purchase an entirely new installation. The figures in Table 8.3 should therefore be taken as illustrative. Precise costs will vary according to the technology chosen. The household-scale technologies would cost significantly more and thus this modelled scheme only considered community-scale technologies as financially viable. Due to the involvement of the manufacturer or supplier throughout the system's lifetime, access to upgrades and repairs should be made easy. It is also the responsibility of the manufacturer or suppliers to remove and recycle all defunct parts and materials, at their expense which needs to be considered in the price of the initial purchase.

8.3.2 Modelling of Revenue Account

Table 8.3 shows modelled figures for recurring expenses over a period of ten years for a community of 100 households. Taking 1% of the median household income as a realistic figure to charge households on a monthly basis, results in a tariff of 45 Rupees/month[3]. According to the field survey (Q110), the maximum amount users are willing to pay (on average) as a monthly tariff for arsenic-free drinking water is R45, the same figure. Delivery is included as standard in this scheme, but a household can opt-out of delivery and save R15 per month if they choose to do so. The wage of the delivery person is R250/mnth with a R15 per house commission (Photo 8.1). The operator receives a wage of R1150/mnth with a commission of R5 per house. Both operator and delivery person are hired on a part-time basis. Assuming a minimum of 50% utilisation of a technology within a village for the first year, the tariff would generate R2250/mnth. Results are based on a 10% increase in utilisation from years 1 to 5 as the technology is promoted by the operator and delivery person. The maximum village utilisation is 90% as the remaining 10% are likely to be households below the poverty line who receive treated water delivered for free. If all the employees (operator and delivery) are women, then no primary breadwinners (typically men) are taken away from their primary work, thus increasing household wage instead of decreasing it. The surplus at the end of ten years can accommodate any increase in costs over that time period.

[3] Khan and Yang (2013) determined that the maximum households in Bangladesh are ‘willing-to-pay’ as a monthly treated-water tariff is 50 BDT which is equal to 41 Indian Rupees.

Photo 8.1 Bicycle rickshaw used for door-to-door water delivery.

Using this model, an initial R10,000 gift or loan of seed money is needed to cover initial operating costs and to be used as a reserve in case any unexpected repairs are required. The system will break even at 80% utilisation at which point the decision can be taken to accumulate profit, repay the loan or save money for system replacement. The initial gift/loan of working capital will be given by the donor of the system and is to be included in the initial capital costs. All costs (including the potential loan), will be managed by the operator and overseen by an all-female water committee.[4]

This model budgets for arsenic testing to be conducted by a laboratory twice per year (R2,500/test). No costs for power are considered in this model, as the technology will be designed to use solar energy that is off-grid and renewable. Only a small financial provision is made for replaceable materials, which assumes the technology will be robust and not require much repair, and that needed chemicals, adsorbents and other consumables are inexpensive. If large repairs are needed, product warranty should be upheld under the extended product responsibility protocols. In the event that a large scale repair is not covered by warranty, or if some other unforeseen need for expenditure arises, the accumulated profit offers a contingency fund.

[4] It has been shown in field practice that a water committee that is entirely female will prove to be more successful than a co-ed or all male committee (Ecofiltro, 2012).

Year	Village Utilisation (%)	Incomings			Outgoings					Net Income (/year)	Cumulative Total
		Household Tariff [+]	Rental/ User Fee [+]	Total [+]	Operator's Wage [-]	Testing 2x/yr [-]	Replaceable Materials [-]	Delivery Costs [-]	Total [-]		
0	0	0	0	0	0	0	0	0	0	**0**	**10000**
1	50	27000	9000	36000	16800	5000	300	12000	-34100	**1900**	**11900**
2	60	32400	10800	43200	17400	5000	300	13800	-34700	**8500**	**20400**
3	70	37800	12600	50400	18000	5000	300	15600	-38900	**11500**	**31900**
4	80	43200	14400	57600	18600	5000	300	17400	-39500	**18100**	**50000**
5	90	48600	16200	64800	19200	5000	300	19200	-43700	**21100**	**71100**
6	90	48600	16200	64800	19200	5000	300	19200	-43700	**21100**	**92200**
7	90	48600	16200	64800	19200	5000	300	19200	-43700	**21100**	**113300**
8	90	48600	16200	64800	19200	5000	300	19200	-43700	**21100**	**134400**
9	90	48600	16200	64800	19200	5000	300	19200	-43700	**21100**	**155500**
10	90	48600	16200	64800	19200	5000	300	19200	-43700	**21100**	**176600**

Table 8.3 Modelled figures for recurring expenses over a period of ten years for 100 households, Rupees.

8.4 Indicators of Economic Capital

The discussions in Sections 8.1 and 8.2 about the actual costs show that though some technologies are making profits, they may be missing important expenses in their model through not paying a fair wage to workers or pricing out the poorest in the community. In this section a set of indicators is described which covers the full range of economic impacts within the village. Thus we are considering impacts which are a financial burden for the village community. Indicators which represent capital costs within the economic store of value are:

- *Initial Capital:* Cost of the purchase and installation of the system and disposal/recycling of the system at end-of-life, as well as seed money to aid in the first few years of operating costs, being pay for externally, increases the likelihood of long term use. 0= Users required to pay all costs; 1= The cost of purchase and installation is paid for by the government or NGO; 2= Cost of purchase, installation, removal and seed money is covered by government or NGO.

- *Future Capital:* Provision to pay the expenses for end-of-life replacement or large scale repair is needed for long-term sustainability.

  0= No plan; 1= Fees paid by users to cover partial costs, or reliance on external body for funds; 2= Stipulation of regular fee paid by users which will pay for all future costs.

The initial capital costs do not form a burden for the community as long as they are not being paid by the user. However less expensive technologies may be deployed in a larger number of villages, which increases regional impact when only a set amount of government or NGO investment is available.

Indicators for recurring income and outgoings are:

- *Viable Monthly Tariff:* A tariff within the economic means of a household aids in the payment of monthly expenses ensuring a system's long-term operation.

  0= free or households are required to pay >1.5% of median monthly income;

  1= 1% to 1.5%; 2= ≤1%.

- *Users below poverty line:* Economic arrangement for free access for people within the community who are below the national poverty line[5] to ensure availability for all demographics.

  0= No arrangement exists; 1= Arrangement exists informally, with the service available only after private discussion. 2= Arrangement is openly advertised, widely known and easy to access.

- *Replaceable Materials:* The cost of all replaceable and/or regenerable materials being accounted for within the budget ensures the continued operation of the technology.

[5] The international poverty line is set at an income level of $1.25 per day (World Bank, 2013). The national poverty line for rural India is set at R816/mnth ($0.34 per day) per person, which is R3264 per month for a family of four (Planning Commission, 2009).

0= Materials are not accounted for; 1= The cost of materials is partially accounted for; 2= Costs of materials are wholly accounted for in the budget or none are required.

- *Power:* Power costs must be accounted for within the budget to enable the system to remain operable. 0= Costs for power are not accounted for in the budget; 1= Costs are only partially accounted for in the budget; 2= Costs are wholly accounted for in the budget or there are no power expenses at all.
- *Lab Testing:* Regular laboratory testing of treated water is included in the budget. 0= No testing accounted for; 1= One test per year budgeted for; 2= >1 test per year is accounted for in the budget.
- *Delivery:* Affordable delivery will increase the convenience of the system, encouraging use. 0= Delivery is not an option; 1= Delivery is available but costs are unaffordable to the average family (≥0.5% of median monthly income);
  2= Delivery is free or available at an affordable price (<0.5% of median monthly income).
- *Wages:* Having everybody in the supply chain (operator, supplier and delivery) paid a fair wage will increase the chances that all operational and maintenance procedures are being followed, improving the likelihood the system will continue to function. 0= No wages; 1= Wages are meant to be paid but are not explicitly budgeted for so may be infrequent; 2= Every person in the supply chain is paid fairly (based on local salaries) and the wage is budgeted for, ensuring the wage is paid regularly.

8.5 Total Scores for Economic Domain and Discussion

The economic indicators for every technology are presented in Table 8.4 and Figure 8.1. They are all given a weighting of one except monthly tariff which has been weighted double because costs (tariff) was rated ‘very important’ in the household survey, and the collection of a fair and affordable tariff is essential for long term sustainability.

BESU scored higher in the Economic Domain than the other technologies, though it still lacks in several important areas. AIIH&PH, PalT/Harbr and CGCRI also ranked relatively highly and the Tipot scored the lowest. The four highest ranking technologies are the only options that generate profit, shown under Net Income in Figure 8.2. Out of the community-scale options in Figure 8.2, the Tipot also generates the greatest loss. The relative ranking of technologies proves to be similar between the total score in the Economic Domain and in Net Profit; however the economic indicators present a more detailed and meaningful contextual understanding of a technology’s economic advantages and disadvantages.

Technology	Capital		Recurring							**Total Score (/100)**
	Initial Capital	Future Capital	Viable Monthly Tariff	Users Below Poverty Line	Replaceable Materials	Power	Lab Testing	Delivery	Wages	
	Coded (/2)	Coded (/2)	Coded (/2) Weight: x2	Coded (/2)	Coded (/2)	Coded (/2)	Coded (/2)	Coded (/2)	Coded (/2)	
Tipot	1	0	0	2	0	0	0	0	0	**15**
IITB	1	0	0	2	0	2	0	0	0	**25**
BESU	1	0	4	1	2	2	1	1	1	**65**
PalT/Harbr	1	0	2	0	2	2	0	0	2	**45**
AIIH&PH	1	0	4	0	2	2	0	0	1	**50**
CGCRI	1	0	0	1	2	2	0	1	1	**40**
Dug	1	1	0	2	0	2	0	0	0	**30**
Sono 45/25	1	0	0	0	2	2	0	0	2	**35**
Nirmal	1	0	4	0	0	2	0	0	0	**35**
DRDO	1	0	4	0	0	2	0	0	0	**35**

Table 8.4 Individual and total scores for economic indicators across all technologies.

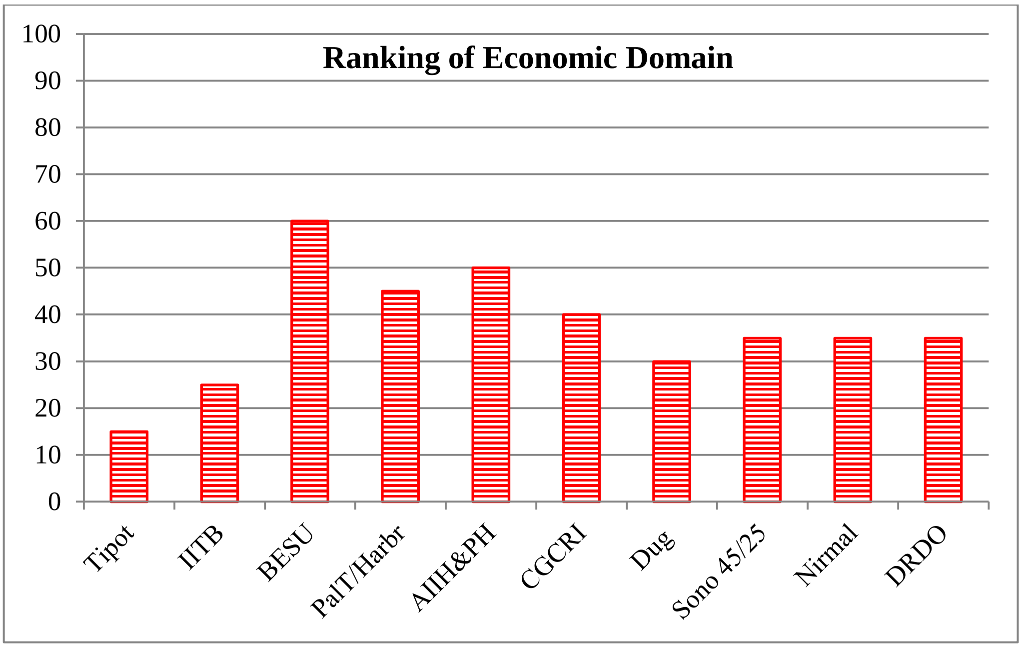

Figure 8.1Total scores for the economic domain.

Similar to the results in the Environmental Domain (Section 7.5; Figure 7.2), there does not seem to be any correlation between the total score of Economic capital for each technology and the percent utilization within the respected villages. There are other considerations, particularly social, that influence usage. This is highlighted by the fact that both the IITB and Tipot are available for free use by everyone yet there is a 50% difference in utilisation (Table 8.2).

Table 8.4 shows that provision for ‘Future Capital’ and ‘Lab Testing’ are rarely included. Having the treated water tested regularly is critical to ensuring proper functionality of a system and in upholding the confidence of the users, and thus needs to be included in the budget. Also, experience shows that the government and NGOs cannot be relied on for long-term village-scale financial support, which means that after initial capital investment, the community needs to share the financial burden of operating and replacing the system. Therefore, provision for system replacement or large scale repairs in the budget is critical to ensure the sustainability of a system into the future. In Section 8.3 a scheme is described which would be economically viable.

This scheme uses the survey results regarding the users ‘willingness to pay’ as a basis for determining a viable tariff. It includes provision for testing and delivery, pays wages where they are needed, and covers all costs. It builds a financial reserve so as to enable investment in replacement equipment.

Ensuring an arsenic-free water source is sustainable requires an affordable and context sensitive economic model for system implementation, operation and replacement. As previously discussed, it will also require significant government involvement and regulation. In particular, a large-scale arsenic-awareness campaign would serve to increase utilization of arsenic mitigation technologies. The creation of extended product responsibility protocols and the development of a toxic waste removal and disposal industry would ensure no further environmental contaminations, lowering the risk of future exposure in communities. Large-scale government regulation and involvement will result in decreased household exposure to arsenic. Decreasing arsenic exposure was shown to benefit households financially, thereby aiding in improving the economy of the entire region. Implementing a sustainable solution to the arsenic problem will not only improve lives through better health but also through the improved financial position of affected households.

9 Aggregation and Conclusions

In this chapter the mitigation options are compared within the context of the triple-bottom-line sustainability assessment. The construction of an aggregated sustainability index is discussed, followed by the final conclusions and recommendations for future work.

9.1 Comparison

Technology	**Sociocultural (/100)**	**Environmental (/100)**	**Economic (/100)**
Tipot	36.6	75.0	15.0
IITB	56.4	40.6	25.0
BESU	53.4	46.8	65.0
PalT/Harbr	53.5	26.6	45.0
AIIH&PH	28.3	31.3	50.0
CGCRI	31.4	25.9	40.0
Dug	46.9	78.1	30.0
Sono 45/25	38.0	15.6	35.0
Nirmal	29.1	18.8	35.0
DRDO	39.1	18.8	35.0

Table 9.1 Total scores for all capital domains are normalised.

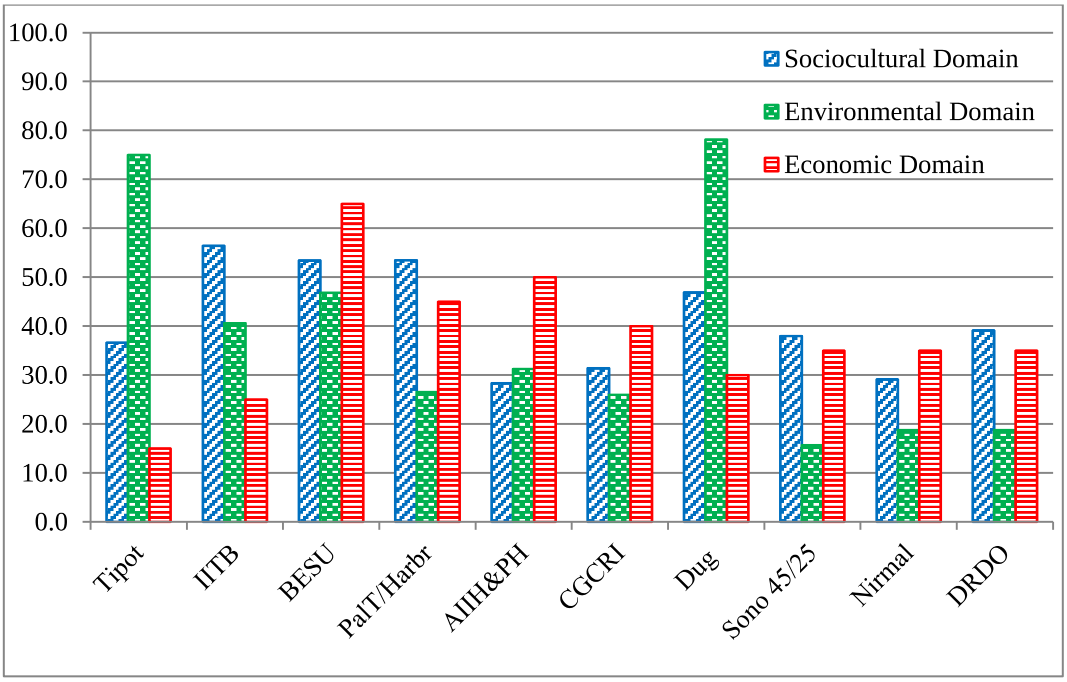

Figure 9.1 Comparing the normalised total scores of all capital for each technology.

The total scores for the three capital domains (Chapters 6, 7 and 8) are shown in Table 9.1. The scores have been normalised each to the scale 0-100, and are presented for comparison in Figure 9.1. Based on these results it can be concluded that not one arsenic mitigation option is sustainable, as defined by this research. BESU ranks relatively highly within all modes of capital, but is only the leader in one domain (economic). Even BESU scores only within 47-62% of the maximum achievable within each capital domain and therefore all technologies demonstrate much scope for improvement. The others score relatively highly in only two of the three capital domains, with often environmental factors proving to be the least valued, except in the cases of Tipot, IITB and Dug wells which all show high scores in the environmental domain, but not in the economic. The AIIH&PH and CGCRI have a clear emphasis on economics but score less well in the other types of capital.

9.2 Aggregation

The total scores for all the capital domains can be aggregated into a sustainability index to determine which technology scores the highest overall. Table 9.2 and Figure 9.2 show a sustainability index composed by averaging the total score from the three domains from Figure 9.1, in other words giving each domain the weighting of 1 and normalising out of one hundred. However when in this form, significant information is lost making it less valuable than the results presented in the three-tiered style shown in Figure 9.1. For example, the sustainability index shows comparable scores between the Tipot and IITB which at first glance would suggest a similarity between them, however the distribution shown in Figure 9.1 illustrates otherwise. The results from the triple-bottom-line breakdown (Table 9.1 and Figure 9.1) can be better used by designers and implementers to make improvements throughout all three stages-of-life.

Technology	**Aggregated Total (/100)**
Tipot	42.2
IITB	40.7
BESU	55.1
PalT/Harbr	41.7
AIIH&PH	36.5
CGCRI	32.4
Dug	51.7
Sono 45/25	29.5
Nirmal	27.6
DRDO	31.0

Table 9.2 Averaged domain scores to create a sustainability index (all three domains given a weighting of 1).

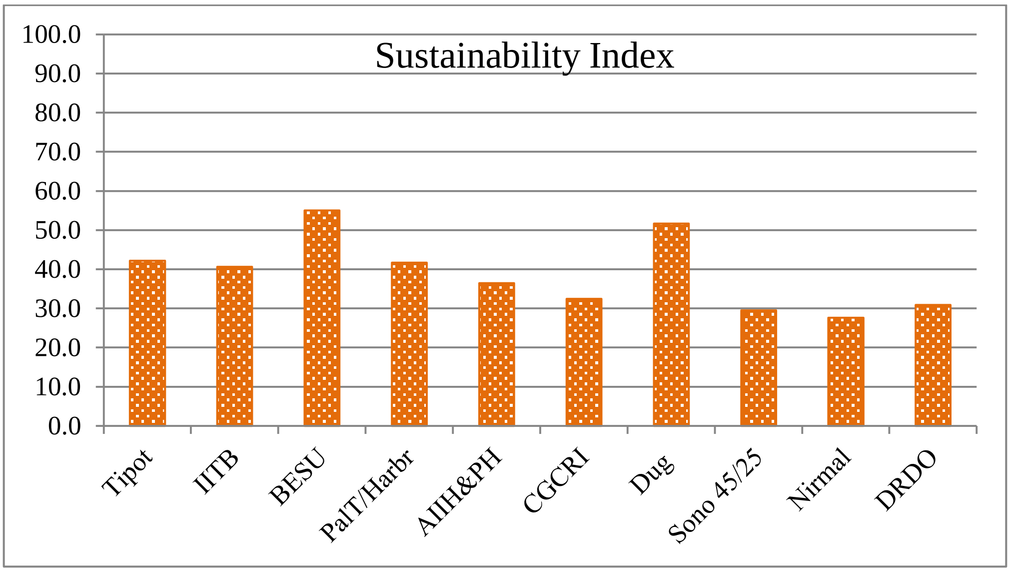

Figure 9.2 Averaged sustainability results for each mitigation option.

Our definition of sustainability (3.3.2) specifies that a mitigation option must meet societal needs, and indeed that is its primary purpose. Fieldwork shows that many technology deployments fail to meet needs adequately, and are either not utilized are quickly abandoned. A composite sustainability index for mitigation options should therefore give a substantial weighting to socio-cultural score. Fieldwork also reveals that, without a plan for financial continuity, the risk of abandonment is again high. Financial provision must also be made for the poorest people, who would otherwise be unable to obtain arsenic-free water. Sustainability must also safeguard the interests of future generations (3.3.2), the chief concern being the accumulation in the local environment of arsenic-rich waste, which is common. Bearing these considerations in mind, in the weighted sustainability index, the sociocultural, environmental and economic domains were weighted 55:15:30 respectively (Table 9.3 and Figure 9.3). This aggregation is more appropriate due to the primary stakeholder (users) highlighting several sociocultural issues and one economic issue as 'very important', and as such were given more weighting than the environmental domain. Figure 9.4 demonstrates the correlation between the weighted sustainability index with percent utilization. Though an appropriately weighted sustainability index may have some utility for policy-makers, the results from Figure 9.1 better highlight areas for improvement for each technology, and thus better explain the widespread failures of mitigation options across this region.

Technology	Sociocultural (x0.55)	Environmental (x0.15)	Economic (x0.30)	**Weighted Total (/100)**
Tipot	20.1	11.3	4.5	35.9
IITB	31.0	6.1	5.8	42.9
BESU	29.4	7.0	19.5	55.9
PalT/Harbr	29.4	4.0	10.4	43.8
AIIH&PH	15.6	4.7	15.0	35.3
CGCRI	17.3	3.9	9.2	30.4
Dug	25.8	11.7	9.0	46.5
Sono 45/25	20.9	2.3	8.1	31.3
Nirmal	16.0	2.8	10.5	29.3
DRDO	21.5	2.8	8.1	32.4

Table 9.3 Domain scores separately weighted and then totalled out of 100.

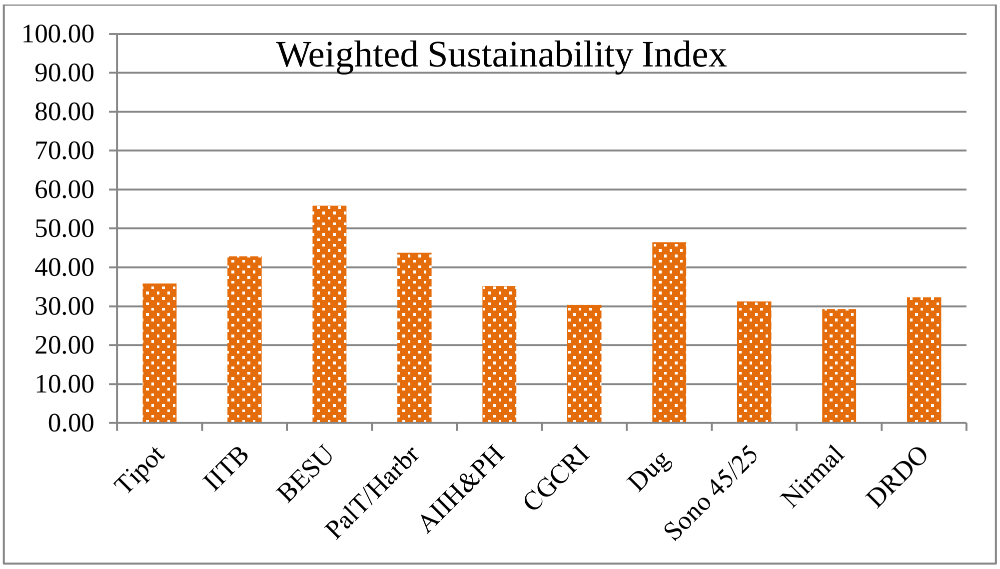

Figure 9.3 Weighted sustainability results for each mitigation option.

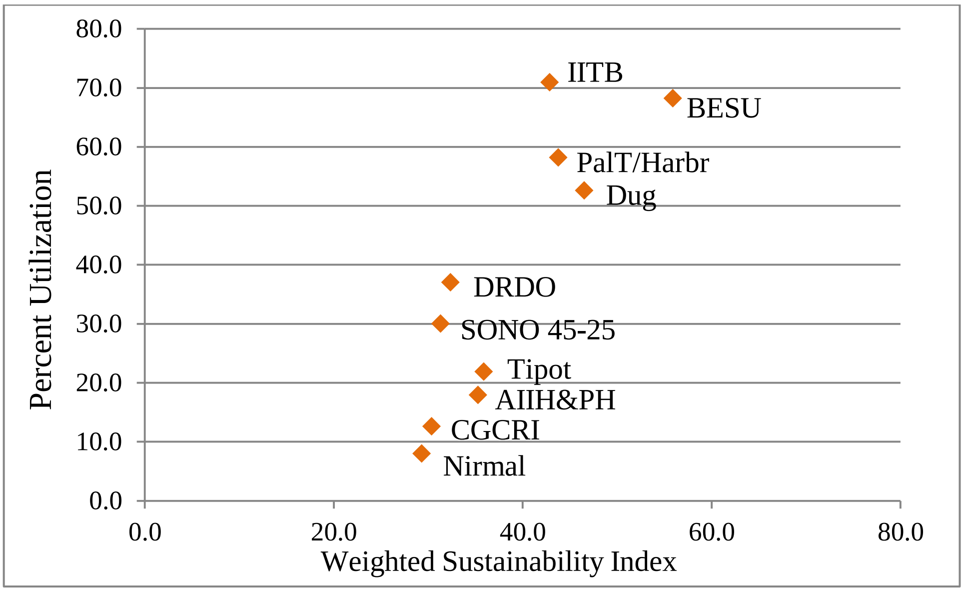

Figure 9.4 Percent utilization plotted against weighted sustainability index.

9.3 Reasons for Failure

The values determined to be ‘very important’ by users were arsenic awareness, trust-confidence, convenience and cost. Three of these four issues are sociocultural and therefore understanding the reasons for failure is mainly related to the sociocultural domain. Technologies which do not score highly in this area tend to be unattractive to potential new users; and if something goes wrong, the technologies are more readily discarded.

Lack of public awareness is one major aspect related to the widespread failure of arsenic-mitigation options. Improving awareness of the arsenic problem in general would result in a better understanding of the need to use a mitigation option. Raising awareness would correct the misconceptions related to the chemical properties of arsenic (ie. arsenic is removed by boiling; arsenic turns water red), and would improve the health knowledge associated with chronic arsenic exposure (like dispelling the confusion with infectious disease). Lastly, awareness programmes would spread a better understanding of the risks associated with arsenic-rich waste changing attitudes to uncontrolled dumping.

Many mitigation options encounter technical problems, but as this research shows, many projects fail despite having the ability to repair or replace because of the poor way the technology is perceived and deployed at village-scale. Table 6.7 highlights the indicators that meet the needs and expectations of the users in Bengal. This suggests the need for community involvement to enhance trust and appropriate product design to boost confidence.

Mitigation options also fail for reasons related to inconvenience. Time spent filtering (flow rate) and time spent walking to the collection site (distance) all take away from the time spent on daily duties. Most stakeholders believed that a range of 0–250 m and 10–30 minutes per trip was a reasonable distance and time for water collection. Therefore any design or implementation feature that will improve the convenience to users will probably improve uptake and continued use of the technology by households.

Cost (tariff) is also a reason for failure, as it is not yet widely accepted that one must pay for treated water because households can obtain untreated water without payment. There is also a connection between the lack of willingness-to-pay and the long latency period of arsenic-related ailments. Stakeholders stressed that regular awareness programs would help to develop the concept of "paying for water" in their rural community.

9.4 Improvements

This section discusses best practice standards as determined in this study, and makes suggestions for improvement in areas of product design, implementation and policy creation.

9.4.1 Product Design

This research concludes that the user-centred approach to design is the most appropriate framework to help understand reasons for failure of arsenic mitigation technologies. This approach suggests that several improvements within the Product Design and Manufacture stage-of-life are required. Designing a product with professional appearance was highlighted as important by the users. Taste and smell (quality) of the treated water, and convenient rate of flow was also stressed. The user prefers the system to have minimal or no maintenance, and to be easy for an untrained person to operate. The technology needs to be designed using parts that are easily accessible to rural villages. A system that is designed to be off-the-grid would solve problems associated with the regular power-outages across the region and be more regularly used. A technology designed to limit the amount and form of toxic waste produced lowers potential community exposure. Overall, these results prove that a transparent, holistic, systematic and user-centred sustainability assessment will provide the information that technology designers and implementers need when considering improvements to ensure satisfactory long-term use.

9.4.2 Implementation

During the Implementation and Operation stage-of-use, strong community involvement is required to ensure sustainability. During the field work, it was observed that systems managed by pre-existing clubs or groups from within the village found general acceptance within the community and were more likely to be trusted by users. A group managing the technology also creates a chain for accountability, which was another issue stakeholders highlighted as important. Households seemed to have less of a problem with paying for treated water when the community club or water committee had a mandate to recirculate the profits back into the community for social benefit, which should be considered best-practice. The sole-proprietor business model was perceived as unfair, because the proprietor took financial benefit from neighbours who needed access to clean water. Users expressed a need for transparency in the system, for operators to be properly trained, for the regular testing of the treated water and public-posting of the results, which all need to be organised at the time of implementation and managed by the water committee. Convenience is vital to utilization. As users made door-to-door delivery or home provision a very high priority, it too must be considered during the implementation and operation phases. To ensure economic viability the users should not be charged more than 1% of their monthly household income to pay for a treated water tariff. The poorest households should not be financial excluded by this tariff and therefore a multi-tiered payment plan (free) must be considered for those who fall below the poverty line. Given the relatively high purchasing costs of systems, having a mitigation option paid for by an external funding body (like the government or NGO) may be the only option at the moment. Recurring and future capital costs can be covered by financial support by the collective village over time, if a viable model like the one outlined in this research is followed. Therefore provision for future system replacement or large repairs must also be considered in the budget and managed by the committee.

9.4.3 Policy Creation

There is a need for strong government involvement in ensuring the sustainability of arsenic mitigation options. The creation of an awareness campaign to encourage and facilitate deployment of mitigation options would improve acceptance amongst users, as their purpose would be better understood and valued more. It was observed that options for safe disposal of arsenic-rich waste were very limited in the rural environment, and that both arsenic-ridden toxic waste and non-toxic municipal waste was often discarded in an uncontrolled manner. This suggests the need for a government enforced waste collection and disposal strategy alongside the implementation of enhanced product responsibility protocols designed to systemically instil product stewardship ideals into the life cycle of mitigation options. Improved public awareness of the levels and dangers of arsenic contamination might change stakeholder opinion on the need for effective disposal protocols, creating public support for such waste regulation. There is also a need for improved guidelines for NGOs, which enforce a standard of best practice in design and implementation of mitigation technologies. These results also show how the sustainability assessment can identify areas where there is a need for increased policy and regulation.

9.5 Summary and Conclusion

In this thesis, the process analysis method is applied to assess the sustainability of options to mitigate arsenic in drinking water in rural India. Stakeholder perspectives, gathered from a fieldwork survey of 933 households in West Bengal in 2012 played a significant role in this assessment. This research found that the 'most important' issues as specified by the technology users are cost, trust, distance from their home to the clean water source (an indicator of convenience), and understanding the health effects of arsenic. It is shown that utilisation of a technology is linearly related to the total sociocultural score and thus measures to improve the sociocultural scores of mitigation projects would help to promote successful deployment of appropriate technology. Attitudes to cost revealed in the surveys are related to the low value placed on arsenic-free water, as also found by other investigators, consistent with a lack of public awareness about the arsenic problem. It is suggested that increased awareness might change attitudes regarding payment of treated water, and towards arsenic-rich waste and its disposal protocols. This waste is often currently discarded in an uncontrolled manner in the local environment, giving rise to the possibility of point-source recontamination. The sustainability assessment includes several trade-offs across the three capital domains, accurately reflecting the complexity of the system. A model based on these findings is outlined, which could be applied with the objective of increasing utilisation and improving sustainability. Of the ten arsenic mitigation systems considered, the BESU technology scored the highest in the assessment, but still only with 47-62% of the maximum scores achievable within each capital domain. It can be concluded that overall, no mitigation technology is deemed to be sustainable and thus explains the widespread failure of mitigation projects across the region. However all hope is not lost, as the indicators in the sustainability assessment show the specific areas of improvement needed for each technology to achieve better scores and to improved long-term viability.

9.6 Future Work

Several areas can be identified for future work. First, more emphasis needs to be put on exploring the level of arsenic awareness in the rural community and on ways to improve it; targeting campaigns to change perceptions (ignorance and misconceptions). Second, more research is needed to create cheaper and more convenient arsenic test kits to allow for widespread water testing. Also, it is known that a country's general level of pro-environmental attitude is directly proportional to economic growth (Owen and Videras, 2006), therefore as standard of living increases in India, so might peoples' attitudes towards the environment. This suggests that a more rigorous eco-analysis within a sustainability assessment might be expected by future users, compared to today. There also needs to be more research into the disposal of arsenic-rich waste. More specifically, the effects of erosion on bricks made from arsenic-rich waste and more site-appropriate leach tests. Additionally, the same sustainability assessment could be completed on surface water filters. This is an arsenic-free option (different to dug wells) that requires mainly bacteria-related treatment. Changing to surface water systems would also require a widespread awareness campaign as using tubewells are rural communities' choice source, not ponds, rivers, lakes, etc. More focus needs to be on this area, to determine to what degree surface water filtration is a sustainable option. Lastly, as naturally-occurring arsenic has been discovered in groundwater throughout Asia and other regions of the world, there is a need to conduct a standardised, user-centred, context-dependant technology assessment, like this one, in these regions also.

Bibliography

Acharyya, S.K., Lahiri, S., Raymahashay, B.C., Bhowmik, A., 2000. Arsenic toxicity of groundwater in parts of the Bengal basin in India and Bangladesh: the role of Quaternary stratigraphy and Holocene sea-level fluctuation. Environmental Geology 39(10), 1127-1137.

Ahmad, J., Goldar, B., Misra, S., 2005. Value of arsenic-free drinking water to rural households in Bangladesh. Journal of Environmental Management 74(2), 173-185.

Ahmad, Z.M., 1972. The social and economic implications of the green revolution in Asia. International Labour Review 105(9).

Ahmed, M.F., Rahaman, M.M., 2000. Water supply and sanitation - Low income urban communities. International Training Network (ITN) Centre, BUET.

Ahmed, M.F., 2001. An overview of arsenic removal technologies in Bangladesh and India. Ahmed, M.F., Ali, M.A., Adeel, Z. (eds), Technologies for Removal of Arsenic from Drinking Water. Tokyo, Japan: United Nations University. Accessed on February 12, 2012 from: http://inweh.unu.edu/archive/Health/docs/Ahmed.pdf

Alaerts, G.J., Khouri, N., 2004. Arsenic contamination of groundwater: Mitigation strategies and policies. Hydrogeology Journal 12, 103–114.

Appelo, C.A.J., Postma, D., 1996. Geochemistry, Groundwater and Pollution, second edition. Amsterdam: Balkema Publishers.

Appelo, C.A.J., Van der Weiden, M.J.J., Tournassat, C., Charlet, L., 2002. Surface complexation of ferrous iron and carbonate on ferrihydrite and the mobilization of arsenic. Environmental Science and Technology 36(14), 3096-3103.

Arora, M., Megharaj, M., Naidu, R., 2009. Arsenic testing field kits: some considerations and recommendations. Environmental Geochemical Health 31, 45-48.

Ashraf, A.M., Badruzzaman, A.B.M., Jalil, M.A., Feroze, A.M., Kamruzzaman, M.D., Azizur-Rahman, M., Al Masud, A., 2003. Fate of arsenic in wastes generated from arsenic removal units. Department of Civil Engineering, Bangladesh University of Engineering and Technology Dhaka. Accessed on March 10, 2013: http://archive.unu.edu/env/Arsenic/Dhaka2003/12-Ali.pdf.

Axinn, W.G., 1991. The influence of interviewer sex on responses to sensitive questions in Nepal. Social Science Research 20, 303–318.

Aziz, S.N., Boyle, K.J., Rahman, M., 2006. Knowledge of arsenic in drinking-water: Risks and avoidance in Matlab, Bangladesh. Journal of Health, Population, and Nutrition 24, 327-335.

Bakshi, A., 2008. A note on household income surveys in India. Indian Statistical Institute. Accessed on February 14, 2012 from: http://www.fas.org.in/UserFiles/File/S5_Bakshi_A_Note_on_Rural_Household_Incomes_in_India.pdf

Bandyopadhyay, S., Kundu, D., Roy, S.N., Ghosh, B.P., Maiti, H.S., 2002. Process for the preparation of arsenic free water, apparatus therefor, method for the manufacture of porous ceramics for use in pressure filtration to produce arsenic free water - Patent granted to CSIR in Bangladesh 1003854.

Banerjee, S., 2008. Dimensions of Indian culture, core cultural values and marketing implications: An analysis. Cross Cultural Management 15(4), 367-378.

Basu, P., Basu, P.O., 2012. Report on the implementation of cost effective house hold arsenic remediation technology in Bihar, West Bengal and UP. Save the Environment NGO. Accessed on March 10, 2013 from: www.stenvironment.com.

Beck, T., 1995. The green revolution and poverty in India: A case study of West Bengal. Applied Geography 15(2), 161-181.

Becker, G.S., 1965. A theory of the allocation of time. The Economic Journal. 75, 493-517.

Becker, S., Feyistan, K., Makinwa-Adebusoye, P., 1995. The effect of sex of interviewers on the quality of data in a Nigerian family planning questionnaire. Studies in Family Planning 26, 233–40.

Bengal Engineering College, 2011. The UNICEF Domestic Filter: Nirmal. Accessed on February 20, 2013 from: http://cs.becs.ac.in/1/2/7/96/999/nirmal.htm.

Benney, M., Riesman, D., Star, S.A., 1956. Age and sex in the interview. American Journal of Sociology 62, 143–52.

Berg, M., Luzi, S., Trang, P.T.K., Viet, P.H., Giger, W., Stuben, D., 2006. Arsenic removal from groundwater by household sand filters: Comparative field study, model calculations and health benefits. Environmental Science and Technology 40, 5567-5573.

Berry, L.L., Seiders, K., Grewal, D., 2002. Understanding service convenience. Journal of Marketing 66, 1-17.

BETV-SAM - Bangladesh Environmental Technology Verification-Support to Arsenic Mitigation program, 2009. Performance monitoring and evaluation of SONO 45-25 arsenic removal technology. Department of Public Health Engineering, Accessed on March 10, 2013 from: http://www.dphe.gov.bd/index.php?option=com_content&view=article&id=65&Itemid=75.

BGS/DPHE/MML, 2001. Arsenic contamination of groundwater in Bangladesh. British Geologic Survey Technical Report Volume 2: Final Report.

Bhattacharya, P., Chatterjee, D., Jacks, G., 1997. Occurrence of arsenic-contaminated groundwater in alluvial aquifers from delta plains, eastern India: Options for safe drinking water supply. International Journal of Water Resources Development 13(1), 79-92.

Bhattacharya, P., Hasan, M.A., Sracek, O., Smith, E., Ahmed, K.M., Bromssen, M.V., Hug, S.M.I., Naidu, R., 2009. Groundwater chemistry and arsenic mobilization in the Holocene flood plains in south-central Bangladesh. Environmental Geochemical Health 31, 23-43.

Bignami-Van Assche, S., Reniers, G., Weinreb, A.A., 2003. An assessment of the KDICP and MDICP data quality: Interviewer effects, question reliability and sample attrition. Demographic Research 1(2), 31–75.

Bissen, M., Frimmel, F.H., 2003. Arsenic - A review. Part II: Oxidation of arsenic and its removal in water treatment. Acta Hydrochimica et Hydrobiologica 31(2), 97-107.

Blanc, A.K., Croft, T.N., 1992. The effect of the sex of interviewer on responses in fertility surveys: The case of Ghana. Population Association of America Annual Meeting Denver.

Bowell, R.J., 1994. Sorption of arsenic by iron oxides and oxyhydroxides in soils. Applied Geochemistry 9, 279-286.

British Geological Survey, 1999. Groundwater Studies for Arsenic Contamination in Bangladesh: Final Report. Mott MacDonald Ltd London, UK.

Brouns, M., Janssen, M., Wong, A., 2013. Dealing with arsenic in rural Bihar, India: Evaluating the successes and failures of mitigation projects and providing a long-term mitigation strategy. Report from Delft University of Technology, The Netherlands.

Brown, L.G., 1989. The strategic and tactical implications of convenience in consumer marketing strategy. The Journal of Consumer Marketing 6(3), 13.

Brundtland G.H., 1987. Our common future: World commission on environment and development. Oxford: Oxford University Press.

Bryman, A., 2012. Social research methods. Oxford: Oxford University Press.

Bukhari, S.A.S., Koondhar, I.D.M., Devrajani, B.T., 1980. Tubewell irrigation system - installation, operation and cost of water. Agricultural Mechanization in Asia 11(1), 37-42.

Caldwell, B., 2003. Tubewells and arsenic in Bangladesh: Challenging a public health success story. International Journal of Population Geography 9, 23-28.

Chakraborti, D., 2001. Fate of three crore rupee arsenic removal plants in Murshidabad. Research report for Swedish Sustainability Foundation accessed on March 17, 2013: http://www.sustainablefuture.se/arsenic/docs/chakraborti-murshidad.pdf

Chakraborti, D., Rahman, M.M., Paul, K., Chowdhury, U.K., Sengupta, M.K., Lodh, D., Chanda, C.R., Saha, K.C., Mukherjee, S.C., 2002. Arsenic calamity in the Indian subcontinent: What lessons have been learned? Talanta 58, 3-22.

Chakraborti, D., Ghorai, S.K., Das, B., Pal, A., Nayak, B., Shah, B.A., 2009. Arsenic exposure through groundwater to the rural and urban population in the Allahabad-Kanpur track in the upper Ganga plain. Journal of Environmental Monitoring 11, 1455-1459.

Chamberlain, J.F., Sabatini, D.A., 2014. Water-supply options in arsenic-affected regions in Cambodia: Targeting the bottom income quintiles, Science of The Total Environment, Available online 21 January 2014.

Chang, Y., Lee, S., Yang, J., 2009. Removal of As(III) and As(V) by natural and synthetic metal oxides. Colloids and Surfaces A: Physicochemical and Engineering Aspects 346(1-3), 202-207.

Chatterjee, A., Das, D., Chakraborti, D., 1993. A study of ground water contamination by arsenic in the residential area of Behala, Calcutta due to industrial pollution. Environmental Pollution 80(1), 57-65.

Chee Tahir A., Darton R.C., 2010. The process analysis method of selecting indicators to quantify the sustainability performance of a business operation. Journal of Cleaner Production 18, 1598-1607.

Cherry, N., Shaikh, K., McDonald, C., Chowdhury, Z., 2008. Stillbirth in rural Bangladesh: arsenic exposure and other etiological factors: a report from Gonoshasthaya Kendra. Bulletin of the World Health Organization 86(3), 172-177.

Clancy, T.M., Hayes, K.F., Raskin, L., 2013. Arsenic waste management: A critical review of testing and disposal of arsenic-bearing solid wastes generated during arsenic removal from drinking water. Environmental Science and Technology 47(19), 10799-10812.

Clarke, T., 2001. Bangladeshis to sue over arsenic poisoning. Nature 413, 556.

Copeland, M.T., 1923. Relation of consumers' buying habits to marketing methods. Harvard Business Review I, 282-89.

Cornwall, D., 2004. Disposal of waste resulting from arsenic removal processes. London: International Water Association.

Cullen, W.R., Reimer, K.J., 1989. Arsenic speciation in the environment. Chemical Reviews 89, 713-764.

Cullen, W.R., 2008. Is arsenic an aphrodisiac? The sociochemistry of an element. The Royal Society of Chemistry Cambridge: Thomas Graham House.

Dalet D., 2012. d-maps.com. Accessed on February 20, 2013: http://d-maps.com/pays.php?lib=west_bengal_maps&num_pay=441&lang=en.

Das, A., 2013. Socio-economic and gender aspects of arsenicosis - A case study in rural west Bengal (India). IOSR Journal Of Humanities And Social Science 13(1), 74-83.

Das, N.K., Sengupta, S.R., 2008. Arsenicosis: Diagnosis and treatment. Indian Journal of Dermatology, Venereology and Leprology 74(6), 571-581.

Department of Information and Cultural Affairs, 1986. Left front government in West Bengal: Nine years. Calcutta: Government of West Bengal.

Derijcke, E., Uitzinger, J., 2006. Residential behaviour in sustainable houses. User Behaviour and Technology Development: Shaping Sustainable relations between Consumers and Technologies. P.P. Verbeek and A. Slob (eds.) Dordrecht, the Netherlands: Springer 119–126.

Dixit, S., Hering, J.G. (2003). Comparison of Arsenic(V) and Arsenic(III) Sorption onto Iron Oxide Minerals: Implications for Arsenic Mobility. Environmental Science & Technology 2003 37 (18), 4182-4189.

Dublin Principles, 1992. World Summit Rio de Janeiro. Accessed on April 15, 2014 from : http://www.wmo.int/pages/prog/hwrp/documents/english/icwedece.html

Duker, A.A., Carranza, E.J.M., Hale, M., 2005. Arsenic geochemistry and health. Environment International 31(5), 631-641.

EAI - Energy Alternatives India: Indian Power Production Scenario, 2012. Accessed on Dec 19, 2013: http://www.eai.in/ref/ae/bio/ipps/india_power_production_scenario.html.

Earle, T.C., Siegrist, M., 2006. Morality information, performance information, and the distinction between trust and confidence. Journal of Applied Social Psychology 36(2), 383-416.

Earle, T.C., 2009. Trust, confidence, and the 2008 global financial crisis. Risk Analysis 29(6), 785-792.

Eaton, A.D., Clesceri, L.S., Rice, E.W., Greenberg, A.E., 1998. Standard methods for the examination of water and wastewater. Washington: American Public Health Association.

Ebi, K.L., Mills, D., Smith, J.B., 2005. A case study of unintended consequences: arsenic in drinking water in Bangladesh. Integration of Public Health with Adaptation to Climate Change. K.L. Ebi, J.B. Smith, and I. Burton (eds.) London: Taylor & Francis 72.

Ecofiltro NGO, 2013. Implementation procedures discussed with Philip Wilson - CEO and Co-Owner. Website: http://ecofiltro.org/en/mission-vision.

Elcik, H., Cakmakci, M., Sahinkaya, E., Ozkaya b., 2013. Arsenic removal from drinking water using low pressure membranes. Industrial & Engineering Chemistry Research 52(29): 9958-9964.

Etmannski, T.R., Darton, R.C., 2013. A methodology for the sustainability assessment of arsenic mitigation technology for drinking water. Science of The Total Environment, Available online 25 November 2013.

Evans, P., 1964. The tectonic framework of Assam. Journal of the Geological Society of India 5, 80-96.

Fendorf, S., Michael, H.A., Van Geen, A., 2010. Spatial and temporal variations of groundwater arsenic in south and Southeast Asia. Science 328, 1123.

Gamper-Rabindran, S., Finger, S.R., 2013. Does industry self-regulation reduce pollution? Responsible care in the chemical industry. Journal of Regulatory Economics 43, 1–30.

Gao, Y., Mucci, A., 2001. Acid base reactions, phosphate and arsenate complexation, and their competitive adsorption at the surface of goethite in 0.7 M NaCl solution. Geochimica et Cosmochimica Acta 65, 2361-2378.

Garelick, H., Dybowska, A., Valsami-Jones, E., Priest, N.D., 2005. Remediation technologies for arsenic contaminated drinking waters. Soils and Sediments 5(3) 182-190.

George, C.M., Factor-Litvak, P., Khan, K., Islam, T., Singha, A., Moon-Howard, J., Van Geen, A., Graziano, J.H., 2013. Approaches to increase arsenic awareness in

Bangladesh: An evaluation of an arsenic education program. Health Education and Behaviour 40(3), 331-338.

German, M., Seingheng, H., SenGupta, A.K., 2013. Mitigating arsenic crisis in the developing world: Role of robust, reusable and selective hybrid anion exchanger (HAIX), Science of The Total Environment, Available online 8 December 2013.

Glanz, K., Rimer, B.K., Viswanath, K., (eds.) 2008. Health behaviour and health education: Theory, research, and practice. San Francisco, CA: Wiley.

GRI Portal - Global Reporting Initiative, 2002. Sustainability reporting guidelines. Amsterdam, Netherland. Website accessed on July 20, 2013: https://www.globalreporting.org/Pages/default.aspx.

Goldberg, S., Johnston, C.T.J., 2001. Mechanisms of arsenic adsorption on amorphous oxides evaluated using macroscopic measurements, vibrational spectroscopy and surface complexation modelling. Colloid Interface Science 234, 204-216.

Government of India, Census Commissioner, 2011. Website accessed on January 21, 2014 http://censusindia.gov.in/Census_And_You/religion.aspx.

Government of India Planning Commission, 2007. Report of the task force on formulating action plan for removal of arsenic contamination in West Bengal, Government of India, New Delhi. Accessed on Dec 19, 2013: http://planningcommission.nic.in/aboutus/committee/wrkgrp11/tf11_arsenics.pdf.

Graedel, T.E., Allenby, B.R., 2003. Industrial Ecology. Englewood Cliffs, New Jersey: Prentice Hall.

Gross, B.L., 1987. Time scarcity: Interdisciplinary perspectives and implications for consumer behaviour. Research in Consumer Behaviour 1-54.

Gupta, S., Mohan, K., Prasad, R., Gupta, S., Kansal, A., 1998. Solid waste management in India: options and opportunities. Resources Conservation and Recycling 24(2), 137-154.

Hanchett, S., Nahar, Q., Van Agthoven, A., Geers, C., Rezvi, M.D.F.J., 2002. Increasing awareness of arsenic in Bangladesh: lessons from a public education programme. Health Policy and Planning 17, 393-401.

Harbauer, 2012. Website accessed on January 5, 2011 from: http://harbauer.in/arsenic-removal-technology.html.

Harvey, C.F., Swartz, C.H., Badruzzaman, A.B.M., Keon-Blute, N., Yu, W., Ali, M.A., Jay, J., Beckie, R., Niedan, V., Brabander, D., Oates, P.M., Ashfaque, K.N., Islam, S., Hemond, H.F., Ahmed, M.F., 2002. Arsenic mobility and groundwater extraction in Bangladesh. Science 298(5598), 1602-1606.

Harvey, C.F., Swartz, C.H., Badruzzaman, A.B.M., Keon-Blute, N., Yu, W., Ali, M.A., Jay, J., Beckie, R., Niedan, V., Brabander, D., Oates, P.M., Ashfaque, K.N., Islam, S., Hemond, H.F., Ahmed, M.F., 2005. Groundwater arsenic contamination on the Ganges delta: biogeochemistry, hydrology, human perturbations, and human suffering on a large scale. Comptes Rendus Geoscience 337(1-2), 285-296.

Hazra, T., Goel, S., 2009. Solid waste management in Kolkata, India: Practices and challenges. Waste Management 29(1), 470-478.

Hilbe, J.M., 2003. A review of current SPSS products. The American Statistician 57(4), 310-315.

Hira Smith, M.M., Hore, T., Chakraborty, P., Chakraborty, D.K., Savarimunthu, X., Smith, A.H., 2003. A dugwell program to provide arsenic-safe water in West Bengal, India: Preliminary results. Journal of Environmental Science and Health A38(1), 289-299.

Hoque, B.A., Hoque, M.M., Ahmed, T., Islam, S., Azad, A.K., Ali, N., Hossain, M., Hossain, M.S., 2004. Demand-based water options for arsenic mitigation: an experience from rural Bangladesh. Public Health 118(1), 70-77.

Hossain, M.A., Sengupta, M.K., Ahamed, S., Rahman, M.M., Mondal, D., Lodh, D., Das, B., Nayak, B., Roy, B.K., Mukherjee, A., Chakraborti, D., 2005. Ineffectiveness and poor reliability of arsenic removal plants in West Bengal, India. Environmental Science and Technology 39, 4300-4306.

Hossain, M.A., Mukherjee, A., Sengupta, M.K., Ahamed, S., Das, B., Nayak, B., Pal, A., Rahman, M.M., Chakraborti, D., 2006. Million dollar arsenic removal plants in West Bengal, India: Useful or not? Water Quality Research Journal Canada 41(2), 216-225.

Hossain, M.A., Rahman, M.M., Murrill, M., Das, B., Roy, B., Dey, S., Maity, D., Chakraborti, C., 2013. Water consumption patterns and factors contributing to water consumption in arsenic affected population of rural West Bengal, India. Science of the Total Environment 463–464, 1217-1224.

Howard, G., 2003. Arsenic, drinking-water and health risk substitution in arsenic mitigation: A discussion paper. World Health Organisation, Accessed on Feb 20, 2012: http://www.who.int/water_sanitation_health/dwq/WSH03.06fulltext.pdf.

Huber , J., 2000. Towards industrial ecology: Sustainable development as a concept of ecological modernization. Journal of Environmental Policy and Planning 2, 269-285.

IIBB – International Institute of Bengal Basin, 2010. Accessed on January 10, 2014 from: http://www.nvo.com/ghosh_research.

IPS - Indian Power Sector, 2013. Overview. Accessed on Dec 19, 2013. http://indianpowersector.com/home/about/.

Jacoby, J., Szybillo, G.J., Berning, C.J., 1976. Time and consumer behaviour: An interdisciplinary overview. Journal of Consumer Research 2, 320-339.

Jain, C.K., Ali, I., 2000. Arsenic occurrence, toxicity and speciation techniques. Water Research 34(17), 4304-4312.

Janz, N.K., Becker, M.H., 1984. The health belief model: A decade later. Health Education and Behaviour 11(1), 1-47.

Jelsma, J., Knot, M., 2002. Designing environmentally efficient services: A script approach. The Journal of Sustainable Product Design 2, 119–130.

Johnston, R..B., Hug, S.J., Inauen, J., Khan, N.I., Mosler, H-J., Yang, H., 2013.Enhancing arsenic mitigation in Bangladesh: Findings from institutional, psychological, and technical investigations. Science of The Total Environment, Available online 28 December 2013.

Johnston, R.B., Hanchett, S., Khan, M.H., 2010. The socio-economics of arsenic removal. Nature Geoscience 3, 2-3.

Kabir, A., Howard, G., 2007. Sustainability of arsenic mitigation in Bangladesh: Results of a functionality survey. International Journal of Environmental Health Research 17(3), 207-218.

Kanel, S.R., Manning, B., Charlet, L., Choi, H., 2005. Removal of arsenic(III) from groundwater by nanoscale zero-valent iron. Environmental Science and Technology 39(5), 1291-1298.

Kameswari, K.S.B., Bhole, A.G., Paramasivam, R., 2001. Evaluation of solidification/stabilization process for the disposal of arsenic-bearing sludge in landfill sites. Environmental Engineering Science 18(3), 167-176.

Khan, N.I., Yang, H., 2013. Arsenic mitigation in Bangladesh: An analysis of institutional stakeholders' opinions, Science of The Total Environment, Available online 2 December 2013.

Khan, N.I., Owens, G., Bruce, D., Naidu, R., 2009. Human arsenic exposure and risk assessment at the landscape level: a review. Environmental Geochemistry and Health 31, 143-66.

Kinniburgh, D.G., Kosmus, W., 2002. Arsenic contamination in groundwater: some analytical considerations. Talanta 58(1), 165-180.

Kristensen, P., 2004. The DPSIR Framework. National Environmental Research Institute Denmark, Department of Policy Analysis.

Leak Bird, 2009. The average monthly household water bill. Accessed on Dec 19, 2013: http://www.leakbird.com/running-toilets/the-average-monthly-household-water-bill-5100-water-facts-and-running-toilets-leakbirdx.

Majumder, A., 2011. Arsenic problem mitigation - West Bengal experience. Accessed on February 20, 2013: http://www.asce.org/uploadedFiles/Regions_Sections_Branches/Region_10/Sections_and_Branches/India_Section/AM_ASCE_Presentation_22.07.2011.pdf.

Malik, A.H., Khan, Z.M., Mahmood, Q., Nasreen, S., Bhatti, Z.A., 2009. Perspectives of low cost arsenic remediation of drinking water in Pakistan and other countries. Journal of hazardous materials 168(1) 1-12.

Mandal, B.K., Suzuki, K.T., 2002. Arsenic round the world: a review. Talanta 58(1), 201-235.

Manning, B.A., Fendorf, S.E., Goldberg, S., 1998. Surface structures and stability of arsenic (III) on goethite: Spectroscopic evidence for inner-sphere complexes. Environment Science and Technology 32(16), 2383-2388.

Mazumder, D.N.G., Chakraborty, A.K., Ghose, A., Gupta, J.D., Chakraborty, D.P., Dey, S.B., Chattopadhyay, N., 1988. Chronic arsenic toxicity from drinking tubewell water in rural West Bengal. Bulletin of the World Health Organization 66(4), 499-506.

Mazumder, D.N.G., Haque, R., Ghosh, N., De, B.K., Santra, A., Chakraborti, D., Smith, A.H., 1998. Arsenic levels in drinking water and the prevalence of skin lesions in West Bengal, India. International Journal of Epidemiology 27, 871-877.

McArthur, J.M., Banerjee, D.M., Hudson-Edwards, K.A., Mishra, R., Purohit, R., Ravenscroft, P., Cronin, A., Howarth, R.J., Chatterjee, A., Talukder, T., Lowry, D., Houghton, S., Chadha, D.K., 2004. Natural organic matter in sedimentary basins and its relation to arsenic in anoxic ground water: the example of West Bengal and its worldwide implications. Applied Geochemistry 19(8), 1255-1293.

Meharg, A.A., Rahman, M.M., 2003. Arsenic contamination of Bangladesh paddy field soils: implications for rice contribution to arsenic consumption. Environmental Science and Technology 37(2), 229-34.

Meharg, A.A., 2005. Venomous Earth: How arsenic caused the world's worst mass poisoning. Macmillan, Houndmills, Basingstoke, Hampshire, New York.

Melamed, D., 2005. Monitoring arsenic in the environment: a review of science and technologies with the potential for field measurements. Analytica Chimica Acta 532(1), 1-13.

Meng, X., Korfiatis, G.P., Christodoulatos, C., Bang, S., 2001. Treatment of arsenic in Bangladesh well water using a household co-precipitation and filtration system. Water Research 35(12), 2805-2810.

Milton, A.H., Hore, S.K., Hossain, M.Z., Rahman, M., 2012. Bangladesh arsenic mitigation programs: lessons from the past. Emerging Health Threats Journal 5.

Mitcham, C., 1995. The concept of sustainable development: its origins and ambivalence. Technology in Society 17(3), 31 l-326.

Mohan, D., Pittman, C.U., 2007. Arsenic removal from water/wastewater using adsorbents-A critical review. Journal of Hazardous Materials 142(1-2), 1-53.

Morgenstern, R.., Pizer, W.A., 2007. Reality check: The nature and performance of voluntary environmental programs in the United States, Europe, and Japan. Washington DC: RFF Press.

Mosler, H., Blöchliger, O.R., Inauen, J., 2010. Personal, social, and situational factors influencing the consumption of drinking water from arsenic-safe deep tubewells in Bangladesh. Journal of Environmental Management 91(6), 1316-1323.

Mukherjee, A., Sengupta, M.K., Hossain, A.M., Ahamed, S., Das, B., Nayak, B., Lodh, D., Rahman, M.M., Chakraborti, D., 2006. Arsenic contamination in groundwater: A global perspective with emphasis on the Asian scenario. Journal of Health Population and Nutrition 24(2), 142-163.

Mukherjee, A., Fryar, A.E., Howell, P.D., 2007. Regional hydrostratigraphy and groundwater flow modelling in the arsenic-affected areas of the western Bengal basin, West Bengal, India. Hydrogeology Journal 15, 1397-1418.

Mukherjee, A., Fryar, A.E., Thomas, W.A., 2009. Geologic, geomorphic and hydrologic framework and evolution of the Bengal basin, India and Bangladesh. Journal of Asian Earth Sciences 34(3), 227-244.

Naqvi, S.M., Vaishnavi, C., Singh, H., 1994. Toxicity and metabolism or arsenic in vertebrates. Arsenic in the environment, Part II: Human health and ecosystem effects, J.O. Nriagu (ed.) New York: Wiley, 55-92.

Naschold, F., 2012. The poor stay poor: Household asset poverty traps in rural semi-arid India. World Development 40(10), 2033-2043.

Ness, B., Urbel-Piirsalu, E., Anderberg, S., Olsson, L., 2007. Categorising tools for sustainability assessment. Ecological Economics 60, 498-508.

Ng, J.C., Wang, J., Shraim, A., 2003. A global health problem caused by arsenic from natural sources. Chemosphere 52, 1353-1359.

Nickson, R.T., McArthur, J.M., Burgess, W., Ahmed, K.M., Ravenscroft, P., Rahman, M., 1998. Arsenic poisoning of Bangladesh groundwater. Nature 395, 338.

Nickson, R.T., McArthur, J.M., Ravenscroft, P., Burgess, W.G., Ahmed, K.M., 2000. Mechanism of arsenic release to groundwater, Bangladesh and West Bengal. Applied Geochemistry 15, 403-413.

Noss, A., 2013. Household income: 2012. Accessed on Dec 19, 2013: http://www.census.gov/prod/2013pubs/acsbr12-02.pdf.

OCETA/ETV Canada/BCSIR, 2009. Bangladesh environmental technology verification support to arsenic mitigation performance: Verification reports, Bangladesh Council of Scientific and Industrial Research/Ontario Center for Environmental Technology Advancement/ETV Canada/CIDA. Website accessed on Aug 26, 2011: http://www.verification-unit.org/etv-am_verified_techs.htm.

Owen, A.L., Videras, J., 2006. Civic cooperation, pro-environment attitudes, and behavioural intentions. Ecological Economics 58(4), 814-829.

Pal, B.N., 2001. Granular ferric hydroxide for elimination of arsenic from drinking water. Accessed on February 20, 2013: http://archive.unu.edu/env/Arsenic/Pal.pdf.

Paul, B.K., 2004. Arsenic contamination awareness among the rural residents in Bangladesh. Social Science and Medicine 59, 1741-1755.

Paul, B.K., Tinnon Brock, V.L., 2006. Treatment delay period: The case of arsenicosis in rural Bangladesh. Health and Place 12(4), 580-593.

Planning Commission of India, 2009. Report of the expert group to review the methodology for estimation of poverty. Accessed on Dec 20, 2013: http://planningcommission.nic.in/reports/genrep/rep_pov.pdf.

Polya, D.A., Charlet, L., 2009. Rising arsenic risk? Environmental Science 2, 383-384.

PSI – Product Stewardship Institute, 2013. Assessed on December 19, 2013 from: http://www.productstewardship.us/displaycommon.cfm?an=1&subarticlenbr=55.

Project Mosquito Net, 2014. Accessed on January 21, 2014 from: http://www.projectmosquitonet.org/.

Public Health Engineering Department, 2012. Arsenic mitigation experience and strategy in West Bengal: Status, strategic actions, key learnings and way forward. Government of West Bengal Booklet from International Conference on Water Quality, Kolkata, 8-9.

Rahman, M.M., Ng, J.C., Naidu, R., 2009. Chronic exposure of arsenic via drinking water and its adverse health impacts on humans. Environmental Geochemical Health 31, 189-200.

Rahman, M.M., Sengupta, M.K., Ahamed, S., Chowdhury, U.K., Lodh, D., Hossain, A., Das, B., Roy, N., Saha, K.C., Palit, S.K., Chakraborti, D., 2005. Arsenic contamination of groundwater and its health impact on residents in a village in West Bengal, India. Bulletin of the World Health Organization 83(1) 49-57.

Rahman, M.M., Chowdhury, U.K., Mukherjee, S.C., Mondal, B.K., Paul, K., Lodh, D., Biswas, B.K., Chanda, C.R., Basu, G.K., Saha, K.C., Roy, S., Das, R., Palit, S.K., Quamruzzaman, Q., Chakraborti, D., 2001. Chronic arsenic toxicity in Bangladesh and West Bengal, India—A review and commentary. Clinical Toxicology 39(7), 683-700.

Raj, D.S.S., Aparna, C., Rekha, P., Bindhu, V.H., Anjaneyulu, Y., 2005. Stabilisation and solidification technologies for the remediation of contaminated soils and sediments: an overview. Land Contamination and Reclamation 13(1), 23-48.

Ravenscroft, P., Brammer, H., Richards, K., 2009. Arsenic Pollution: A Global Synthesis. Chichester, West Sussex: Wiley-Blackwell Publishing.

Rees, W.E., 1992. Ecological footprints and appropriate carrying capacity: What urban economics leaves out. Environment and Urbanization 4(2), 121-137.

Roberts, L.C., Hug, S.J., Ruettimann, T., Billah, M.M., Khan, A.W., Rahman, M.T., 2004. Arsenic removal with iron (II) and iron (III) in waters with high silicate and phosphate concentrations. Environmental Science and Technology 38(1), 307-315.

Rodríguez, E., Boks, C., 2005. How design of products affects user behaviour and vice versa: the environmental implications. Proceedings of EcoDesign Tokyo: Union of Ecodesigners, 1–8.

Roy, J., 2008. Economic benefits of arsenic removal from ground water — A case study from West Bengal, India. Science of the Total Environment 397(1–3), 1-12.

Roy, S.N., Dey, T., Majumder, M., Majumder, S., Ghosh, B.P., Bandyopadhyay, S., Maiti, H.S., 2005. Ceramic membrane and water purification. Indian Science News Association Journal of Science and Culture 71(5-6), 159-157.

Safarzadeh-Amiri, A., Fowlie, P., Kazi, A.I., Siraj, S., Ahmed, S., Akbor, A., 2011. Validation of analysis of arsenic in water samples using Wagtech Digital Arsenator. Science of the Total Environment 409(13), 2662-2667.

Saha, J.C., Dikshit, K., Bandyopadhyay, M., 2001. Comparative studies for selection of technologies for arsenic removal from drinking water. Technologies for Removal of Arsenic from Drinking Water. M.F. Ahmed, M.A. Ali, Z. Adeel (eds.), Tokyo, Japan: United Nations University, 76.

Saha, K.C., 1984. Melanokeratosis from arsenical contamination of tubewell water. Indian Journal of Dermatology 29(4), 37-46.

Saha, K.C., 2003. Saha's grading of arsenicosis progression and treatment. Arsenic Exposure and Heath Effects, W.R. Chappell, C.O. Abernathy, R.L. Calderon, D.J. Thomas, V Edn, (eds.) Amsterdam: Elsevier, 391-414.

Samanta, G., Chowdhury, T.R., Mandal, B.K., Biswas, B.K., Chowdhury, U.K., Basu, G.K., Chanda, C.R., Lodh, D., Chakraborti, D., 1999. Flow injection hydride generation absorption spectrometry for determination of arsenic in water and biological samples from arsenic-affected districts of West Bengal, India, and Bangladesh. Microchemical Journal 62, 174–191.

Sankararamakrishnan, N., Chauhan, D., Nickson, R.T., Tripathi, R.M., Iyengar, L., 2008. Evaluation of two commercial field test kits used for screening of groundwater for arsenic in Northern India. Science of the Total Environment 401(1-3), 162-167.

SAR – Subterranean Arsenic Removal Technology, 2010. Website accessed on November 15, 2010 from: http://www.insituarsenic.org/principle.html.

Sarkar, A., 2010. Assessing vulnerability of the arsenic exposed population in India. Asian Journal of Water, Environment and Pollution 7(1), 35-43.

Sarkar, S., Gupta, A., Biswas, R.K., Deb, A.K., Greenleaf, J.E., Sen Gupta, A.K., 2005. Well-head arsenic removal units in remote villages of Indian subcontinent: Field results and performance evaluation. Water Research 39(10), 2196-2206.

Sarkar, S., Blaney, L.M., Gupta, A., Ghosh, D., Sengupta, A.K., 2008. Arsenic removal from groundwater and its safe containment in a rural environment: validation of a sustainable approach. Environmental Science and Technology 42(12), 4268-4273.

Sarkar, S., Greenleaf, J.E., Gupta, A., Ghosh, D., Blaney, L.M., Bandyopadhyay, P., Biswas, R.K., Dutta, A.K., Sengupta, A.K., 2010. Evolution of community-based arsenic removal systems in remote villages in West Bengal, India: Assessment of decade-long operation. Water Research 44(19), 5813-5822.

Sato, Y., Kang, M., Kamei, T., Magara, Y., 2002. Performance of nanofiltration for arsenic removal. Water Research 36, 3371-3377.

Sen Gupta, B., Chatterjee, S., Rott, U., Kauffman, H., Bandopadhyay, A., DeGroot, W., Nag, N.K., Carbonell-Barrachina, A.A., Mukherjee, S., 2009. A simple chemical free arsenic removal method for community water supply - A case study from West Bengal, India. Environmental Pollution 157(12), 3351-3353.

Shafiquzzaman, M., Azam, M.S., Mishima, I., Nakajima, J., 2009. Technical and social evaluation of arsenic mitigation in rural Bangladesh. Journal of Health, Population and Nutrition 27, 674–83.

Sharmin, N., 2001. Arsenic removal processes on trial in Bangladesh. Technologies for Removal of Arsenic from Drinking Water, M.F. Ahmed, M.A. Ali, Z. Adeel (eds.), Tokyo, Japan: United Nations University.

Smedley, P.L., Kinniburgh, D.G., 2002. A review of the source, behaviour and distribution of arsenic in natural waters. Applied Geochemistry 17(5), 517-568.

Smedley, P.L., Kinniburgh, D.G., 2005. Arsenic in groundwater and the environment. Essentials of Medical Geology: Impacts of the Natural Environment on Public Health, O. Selinus (ed.), Amsterdam: Elsevier, 263.

Smit, E., Stevels, A., Sherwin, C., 2002. User centred ecodesign: Experiences from the design of a human-powered remote control. Proceedings of Care Innovation, Vienna: IEEE.

Smith, A.H., Ercumen, A., Yuan, Y., Steinmaus, C.M., 2009. Increased lung cancer risks are similar whether arsenic is ingested or inhaled. Journal of Exposure Science and Environmental Epidemiology 19(4), 343-348.

Smith, A.H., Lingas, E.O., Rahman, M., 2000. Bulletin World Health Organization.

Smith, T.W., Axon, C.J., Darton, R.C., 2013. A methodology for measuring the sustainability of car transport systems. Transport Policy 30, 308–317.

Stenehjem, A., Vahter, M., Nermell, B., Aasen, J., Lierhagen, S., Mørland, J., Jacobsen, D., 2007. Slow recovery from severe inorganic arsenic poisoning despite treatment with DMSA (2.3-dimercaptosuccinic acid). Clinical Toxicology 45(4), 424-428.

Sullivan, C., Tyrer, M., Cheeseman, C.R., Graham, N.J.D., 2010. Disposal of water treatment wastes containing arsenic - a review. The Science of the Total Environment 408(8), 1770-1778.

Swedlund, P.J., Webster, J.G., 1999. Adsorption and polymerisation of silicic acid on ferrihydrite, and its effect on arsenic adsorption. Water Resources 33(16), 3413-3422.

Taylor, S., 1994. Waiting for service: The relationship between delays and evaluations on service. Journal of Marketing 58, 56-69.

Toman, M.A., 2009. The difficulty in defining sustainability. Resources 106, 3-6.

Turpeinen, R., 2002. Interactions between metals, microbes and plants – Bioremediation of arsenic and lead contaminated soils. Dissertation from University of Helsinki.

Umitsu, M., 1987. Late quaternary sedimentary environment and landform evolution in the Bengal lowland. Geographical Reviews of Japan B60, 164-178.

Umitsu, M., 1993. Late quaternary sedimentary environments and landforms in the Ganges Delta. Sedimentary Geology 83, 177-186.

UNDP – United Nations Development Programme, 2006. Human development report beyond scarcity: power, poverty and the global water crisis. Accessed on Dec 19, 2013: http://hdr.undp.org/sites/default/files/hdr_2006_summary_en.pdf.

UNFPA – United Nations Population Fund, 2012. Preventing HIV/AIDS. Accessed on January 21, 2014 from : http://www.unfpa.org/hiv/programming.htm.

UNICEF, 2000. Media Brief: Arsenic Mitigation in Bangladesh. Accessed on Feb 20, 2013: http://www.unicef.org/bangladesh/Arsenic.pdf.

UNICEF, 2010. Monitoring arsenic in water: Review of test kits. Technical Bulletin 8. Accessed on February 20, 2013:
http://www.unicef.org/supply/files/Monitoring_Arsenic_in_Water.pdf.

United Nations Statistics Division, 2005. Designing household survey samples: practical guidelines. Department of Economic and Social Affairs, New York, Series F(98).

Vahter, M., 2009. Effects of arsenic on maternal and fetal health. Annual Review of Nutrition 29, 381-399.

Van Geen, A., Ahmed, E.B., Pitcher, L., Mey, J.L., Ahsan, H., Graziano, J.H., Ahmed, K.M., 2014. Comparison of two blanket surveys of arsenic in tubewells conducted 12 years apart in a 25km2 area of Bangladesh. Science of The Total Environment, Available online 16 January 2014.

Van Geen, A., Ahsan, H., Horneman, A.H., Dhar, R.K., Zheng, Y., Hussain, I., 2002. Promotion or well-switching to mitigate the current arsenic crisis in Bangladesh. Bulletin of the World Health Organization 80, 732-737.

Van Geen, A., Cheng, Z., Seddique, A.A., Hoque, M.A., Gelman, A., Graziano,J.H., Ahsan, H., Parvez, F., Ahmed, K.M., 2005. Reliability of a commercial kit to test groundwater for arsenic in Bangladesh. Environmental Science and Technology 39(1), 299-303.

Voli, P.K., 1998. The convenience orientation of services consumers: An empirical examination. Doctoral dissertation, College of Business and Public Administration, Old Dominion University.

Vredenburg, K., Isensee, S., Righi, C., 2002. User-centred design; An integrated approach. Upper Saddle River, NJ: Prentice-Hall.

Wang, C.H., Hsiao, C.K., Chen, C.L., 2007. A review of the epidemiologic literature on the role of environmental arsenic exposure and cardiovascular diseases. Toxicology and Applied Pharmacology 222, 315-326.

WBDID - World Bank Development Indicators Database, 2006. Accessed on January 15, 2014 from : http://data.worldbank.org/indicator.

Wegelin, M., Gechter, D., Hug, S., Mahmud, A., Motaleb, A., 2000. SORAS - A simple arsenic removal process. Accessed on February 20, 2013: http://www.sswm.info/sites/default/files/reference_attachments/WEGELIN%20et%20al%201999%20SORAS%20A%20Simple%20Arsenic%20Removal%20Process.pdf.

Weinreb, A.A., 2006. The limitations of stranger-interviewers in rural Kenya. American Sociological Review 71(6), 1014-1039.

WHO, 2001. Arsenic in drinking water: Fact sheet 210. Bulletin of the World Health Organization 78(9), 1096.

WHO, 2004. Guidelines for drinking-water quality. World Health Organization 3(1).

Williams, P.N., Islam, M.R., Adomako, E.E., Raab, A., Hossain, S.A., Zhu, Y.G., Feldmann, J., Meharg, A.A., 2006. Increase in rice grain arsenic for regions of Bangladesh irrigating paddies with elevated arsenic in groundwaters. Environmental Science and Technology 40(16), 4903-8.

World Bank, 1998. The Bangladesh Arsenic Mitigation Water Supply Project: Addressing a massive public health crisis. Accessed on February 20, 2013: http://web.worldbank.org/external/projects/main?pagePK=104231&piPK=73230&theSitePK=40941&menuPK=228424&Projectid=P050745.

World Bank, 2013. Poverty and equity. Accessed on Dec 19, 2013: http://povertydata.worldbank.org/poverty/country/IND.

Young, E., 1996. Cleaning up arsenic and old waste. New Scientist 22.

Appendix I: Summarized Field Notes

TiPOT

Scale:	Community
# of Units Visited:	2
As Removal Mechanism:	In-situ (Aquifer) ‘Biochemical’ Remediation
Pump:	Submersible Electric
Construction Materials:	Small building (3m x 3m x 3.5m) with brick and plastered walls, a tin roof and lockable wooden door houses the power switch (only). System is comprised of two 4000L high density ‘polyege’ storage containers (black), pipes are pvc or galvanised and a pump. All materials purchased new from a local town.
Estimated Lifespan:	10 years? (Aquifer not tested or modelled for long-term use)

Village Code: Tipot1:1 **Visited on: July 19 & 20, 2012**

Background

Village Name:	Merudandi *para*
Location:	Basirhat, North 24 Parganas, West Bengal, India
GPS:	N22°41.306’ E088°53.161’
Religion:	Hindu
Total Households in Community:	<100
Total Household Surveyed:	35
Mean Household Income for Village:	6,600 Rupees (~$110 USD) /month
Mean # People/Household:	4.89
Mean # Children/Household:	0.89
Type of Local Water Sources Used by Villagers:	Household shallow tube wells, Ponds

Installation

Date:	2008
Duration:	3 months to construct the system but >1 year for the aquifer reclamation process to be completed
Process:	NGO approached *Panchayat* who donated land for the building. No other community members involved in decision through a council, club or stakeholder meetings
Location:	Near the centre of town
Cost:	420,000 Rupees ($7,000 USD), NGO paid entire amount through World Bank donation

Operation

[As] in Raw Water:	Inaccessible to take a sample. Household tube well sample from <10m away from system showed <10ppb of arsenic (depth unknown)
[As] in Treated Water:	Below Detectable Limit
Flow Rate:	High-flow tap with no delay (comes from a storage tank)
Vol of Treated Water Produced/Day:	4000 Litres max
Daily Treatment Time:	1.5 hours/day
Daily Operation Procedure:	The operator turns on the power and the pump. He fills the storage tank full, and the recharge tank half full. Each tank holds 4000L.The water in the recharge tank is blown through a shower head at the top of the tank before entering the tank. Oxygen also enters through holes in the side of the tank. Oxygen rich water fills half the tank and then gets fed back down into the well.
Reoccurring Costs:	250 Rupees ($4 USD)/month (for electricity only)
Details on Operator(s):	Only one person was trained; He is the brother of *Panchayat* and volunteers his time
Maintenance Procedure:	Maintenance includes tightening of bolts and valves regularly, draining the tanks and cleaning the inside of the tanks with a scrub brush (no soap or chemicals used).

Maintenance Schedule: 1 hour/month for cleaning
Operator Training: Operator was trained informally for 1.5 months by the Queens Uni Belfast team
Power Outages: 4-5 hours/day at random times, intermittently; totally unpredictable
Frequency of Arsenic Testing: 2 tests/month initially until the concentration stabilized and now is 1 test/month
Arsenic Test Results Posted Publicly: No
Visual Public Notice: Painted on building: "World Bank Project, Subterranean Arsenic Removal: From Experiment to Delivery. Recipient Organisation: Ramakrishna Vivekananda Mission, Barrackpore, N24 PGs" No contact information (phone number); All in English (not Bangla); No information about the arsenic problem/symptoms or how system works.

Waste

Volume: No arsenic-ridden waste produced during operation or maintenance. No disposable or regenerable parts used in system

Feedback/Notes

Accountability: Operator has no boss or committee to oversee that he is doing the maintenance properly. There is nobody the villagers can contact when they have questions or concerns about the system.

Corruption: "Operator is now asking for money to pay for power but never did for previous 3 years. He says the money has run out but we don't believe him." (I researched the NGO, called and asked about this and it is true that the funding from the World Bank has run out so now there is nobody to pay for the electricity)

Satisfaction: "Water smells and tastes strange"

Awareness: After drinking the arsenic & iron contaminated water for a long time, the villagers may take some time to adapt to the taste of the good quality As & Fe free water. This will need some awareness campaign. Also, absence of iron results in loose motion for a few days which can be mistaken as stomach upset.

Level of understanding: Many people have died or arsenic related cancers here but still many people do not know what arsenic is and had many questions about how the system actually works

Reliability/Durability: System was operational during visit and has never broken down in villagers memory

Trust: Many villagers commented on the fact the *Panchayat* and his family do not use the filter, so they feel the water must therefore not be drinkable

Photo: Tipot1:1

Village Code: Tipot 1:2 **Visited on: August 17, 2012**

Background

Village Name:	Gotra *para*
Location:	Ghetugachi, Chakdah, Nadia, West Bengal, India
GPS:	N23°01.295’ E088°34.994’
Religion:	Muslim
Total Households in Community:	<100
Total Household Surveyed:	40
Mean Household Income for Village:	3,500 Rupees (~$58 USD)/month
Mean # People/Household:	4.53
Mean # Children/Household:	0.85

Type of Local Water Sources Used by Villagers: Household shallow tube wells, Ponds, One public deep tube well located at one end of town that has a government sign above it saying it is arsenic free (English & Bengla).

Installation

Date:	2009
Duration:	1 month to construct the system but 8 months for the aquifer reclamation process to be completed
Process:	NGO approached *Panchayat* to find someone to donate land. No other community members involved in decision through a council, club or stakeholder meetings
Location:	Along the main road near one end of the village
Cost:	420,000 Rupees (~$7,000 USD) -NGO paid entire amount through World Bank donation

Operation

[As] in Raw Water:	Inaccessible to take a sample. Public tube well 50m away from system as tested and showed 200ppb of arsenic but depth is unknown.
[As] in Treated Water:	<10ppb
Flow Rate:	High-flow tap with no delay (comes from a storage tank)
Vol of Treated Water Produced/Day:	4000 Litres max
Daily Treatment Time:	1.5 hours/day
Daily Operation Procedure:	Same as above system: Tipot 1:1
Reoccurring Costs:	400 Rupees ($7 USD)/month (for electricity only) Operator charging <u>some</u> families 15 Rupees (~$0.25 USD) /month for use of the water from the system
Details on Operator(s):	Operator donated land, so that is how he became in charge of the system and now he and his family live in the filter building.
Maintenance Procedure:	Operator doesn’t feel it’s necessary to wash the storage tanks so doesn’t
Maintenance Schedule:	None
Operator Training:	Operator was trained informally for 1 month by the Queens Uni Belfast team
Power Outages:	4-5 hours/day at random times, intermittently; totally unpredictable
Frequency of Arsenic Testing:	Is not currently tested
Arsenic Test Results Posted Publicly:	No
Visual Public Notice:	Painted on building: “World Bank Project, Subterranean Arsenic Removal: From Experiment to Delivery. Recipient Organisation: Ramakrishna Vivekananda Mission, Barrackpore, N24 PGs” No contact information (phone number); All in English (not Bengla); No information about the arsenic problem/symptoms or how system works.

Waste

Volume:	No arsenic-ridden waste produced during operation or maintenance. No disposable or regenerable parts used in system

Feedback/Notes

Accountability: Operator has no boss or committee to oversee that he is doing the maintenance properly. There is nobody the villagers can contact when they have questions or concerns about the system.

Corruption: The operator is not well liked or respected in the community. He charges some families to use the water but not all. He also refused to clean the system saying that it's not needed. He was also very rude and uncooperative towards myself and my team
Satisfaction: Villagers said that the water has a bad taste and it is often too hot to drink. Villagers also said the water is iron-rich (because it turns the water red).
Awareness: People seem generally aware of the arsenic problem in their area however some seem to be mixing up iron (red water) with arsenic
Level of understanding: People have no idea how the system works but were generally uninterested
Reliability/Durability: System was operational during my visit however most of the villagers believe there to be arsenic in the 'treated' water so did not use it for drinking.
Trust: I was told that since the Operator washes his cow using the system's water, it is therefore not clean water or drinkable because if it was, he wouldn't waste it washing his cow. He would wash it in the pond like everyone else. Also one villager said that they asked to see a report which states the concentration of arsenic in the treated water and since the operator couldn't produce one, they use the deep tube well on the other side of town instead because its certified.

Photo: Tipot 1:2

IITB

Scale:	Community (300 families max)
# of Units Visited:	3
As Removal Mechanism:	Sorption using iron nails which forms hydrous ferric oxide
Pump:	Hand – no power required
Construction Materials:	Two (or three) metal tanks (1m x 1m x 1.5m), one on the ground and the other(s) on concrete legs. Flow pipes are pvc tubing and tap is metal. Iron nails in a metal tray at the top. All materials purchased locally
Estimated Lifespan:	5-10 years (uncertain)

Village Code: IITB 2:1 **Visited on: July 24, 2012**

Background

Village Name:	Sonatheli *para*
Location:	Nadia, West Bengal, India
GPS:	N22°59.929' E088°33.251'
Religion:	Hindu
Total Households in Community:	~100
Total Household Surveyed:	31

Mean Household Income for Village: 4,300 Rupees (~$72 USD) /month
Mean # People/Household: 6.10
Mean # Children/Household: 1.35
Type of Local Water Sources Used by Villagers: Household shallow tube wells, 3 stand pipes of municipal water scattered across village but people complain of digestive problems with this water, and ponds are used for non-drinking purposes

Installation

Date: 2010
Duration: ~1 week to build
Process: Locations chosen by IITB as these systems were initially trials so they requested permission from the local *Panchayat* . Unknown process as to how the land was aquired. No community council, or stakeholder feedback sought (because it wasn't a development project, it was field trials of a technology)
Location: Near the center of town along the main road
Cost: 80,000 Rupees ($1,300 USD) max

Operation

[As] in Raw Water: >100 ppb
[As] in Treated Water: <10 ppb
Flow Rate: ~2 minute delay from pumping to flow out the tap (=100L/hr)
Vol of Treated Water Produced/Day: ~2000 L/day
Daily Treatment Time: Treatment done 'to-order' by each individual pumping what they need
Daily Operation Procedure: User pumps for a few mins, waits, then fills container from tap on tank
Reoccurring Costs: ~1200 Rupees max ($20 USD) / year for iron nails and hand pump repair
Details on Operator(s): (Mr Ghosh) is a villager who was trained by IIT Bombay
Maintenance Procedure: Volunteers wash nails once every month and clean the first tank up to a depth of 40 cm from the top once /3-4 months
Maintenance Schedule: See 'maintenance procedure'
Operator Training: Informally trained over several months and multiple visits of IIT Bombay
Frequency of Arsenic Testing: Unknown
Arsenic Test Results Posted Publicly: No
Visual Public Notice: "Arsenic Removal Unit designed & installed by IIT Bombay India on 24/1/2008; Funded by Dept of Science & Technology, Govt of India" in English with no contact information or explanation of how the system works.

Waste

Volume: Arsenic-rich sludge dried = 35 kg/year
Type: Arsenic-rich sludge and precipitate from nails
Disposal Location(s): Dumped in a marshy area immediately behind the filter
Disposal Cost: Free (dumped)

Feedback/Notes

Accountability: Operator was paid by IITB for a few years and they checked in with him regularly however IITB didn't make their info public so regular villagers could only come to them with potential concerns while there were visiting the site.
Corruption: Household expressed concern that perhaps the operator was requesting money for repairs but keeping it instead
Satisfaction: People who own the land that the filter is on want to be paid for their land because " they are poor" and it was taken without compensation
Awareness: Variable awareness in community about the local arsenic problem and phys effects
Level of understanding: Operator very well versed in how system operates, general public very much less so Reliability/Durability: The system has only required small repairs and has never been offline since it's instalment (except during cleaning)
Trust: Operator is widely known and trusted in the community

Photos: IITB 2:1 and the pond of waste that sits behind it.

Village Code: IITB 2:2 **Visited on: July 25, 2012**

Background
Village Name: Sonakhali Biswas *para*
Location: Nadia, West Bengal, India
GPS: N23°00.266’ E088°33.132’
Religion: Muslim
Total Households in Community: 60-80
Total Household Surveyed: 37
Mean Household Income for Village: 5,000 Rupees (~$83 USD) /month
Mean # People/Household: 4.84
Mean # Children/Household: 1.19
Type of Local Water Sources Used by Villagers: For drinking people mostly use public tube wells that the Panchayat drilled (2 exist scattered across village) and/or the filter; Household shallow tube wells, 2 stand pipes of municipal water and ponds are used for non-drinking purposes

Installation
Date: 2010
Duration: 4-6 weeks to build
Process: Locations chosen by IITB as these systems were initially trials so they requested permission from the local *Panchayat* and the land was donated by one of the wealthier villagers. A local water committee was formed but was inactive at the time or this survey
Location: At one end of town behind a villager’s house (far off the main road) beside a stream/river
Cost: 80,000 Rupees (~$1,300 USD) max

Operation
[As] in Raw Water: 100-200 ppb
[As] in Treated Water: <10 ppb
Flow Rate: ~2 minute delay from pumping to flow out the tap (=100L/hr)
Vol of Treated Water Produced/Day: ~2000 L/day
Daily Treatment Time: Treatment done ‘to-order’ by each individual pumping what they need
Daily Operation Procedure: User pumps for a few mins, waits, then fills container from tap on tank

Reoccurring Costs: ~1200 Rupees max (~$20 USD) / year for iron nails and hand pump repair
Some families pay 10 Rupees ($0.17 USD) / month for maintenance costs
Details on Operator(s): Family that own the land unofficially oversee the operation and maintenance
Maintenance Procedure: Men wash nails once every month and clean the first tank up to a depth of 40 cm from the top once /3-4 months and are paid 50 Rupee ($0.83 USD) per cleaning
Maintenance Schedule: Takes approx. 3 hours to complete washing of tanks, rocks and nails
Operator Training: Family informally trained during multiple visits of IIT Bombay people and father trained directly by Mr Ghosh
Frequency of Arsenic Testing: Weekly by an unknown group
Arsenic Test Results Posted Publicly: No

Visual Public Notice: “Arsenic Removal Unit designed & installed by IIT Bombay India 2010; Funded by Dept of Science & Technology, Govt of India” in English with no contact information or explanation of how the system works.

Waste

Volume: Arsenic-rich sludge dried = 35 kg/year and ~1 kg of nails / month

Type: Arsenic-rich sludge and precipitate from nails

Disposal Location(s): Dumped into a covered tank that has gravel chips inside. Tank is damaged at the bottom so fluid drains out to the adjacent stream/pond, or they dump straight into the stream/pond

Disposal Cost: Free (dumped)

Feedback/Notes

Accountability: There is no water filter committee so there is no way to hold anyone accountable for proper and/or regular maintenance

Corruption:

Satisfaction: Multiple comments from people who do not use the filter because ‘it is located in the Muslim area of town’ and they is Hindu, “and think Muslims feel angry towards Hindus so it is unsafe”

Awareness: Confusion with arsenic with iron

Level of understanding: Operator very prideful about filter and has a clear sense of ownership over it

Reliability/Durability: The system has only required small repairs and has never been offline since its instalment (except during cleaning)

Trust: Many people’s reasons to not use it was because its inconvenient and too far to walk from their house, especially when the public deep tube well is closer and doesn’t give them loose movements

Photos: IITB 2:2 and the open-air waste container that sits beside it.

Village Code: IITB 2:3 **Visited on: July 26, 2012**

Background

Village Name: Polasi Rani *para*

Location: North 24 Paraganas, West Bengal, India

GPS: N22°55.159’ E088°29.424’

Religion: Tribal

Total Households in Community: 100-150

Total Household Surveyed: 33

Mean Household Income for Village: 7,800 Rupees (~$130 USD) /month

Mean # People/Household: 5.30

Mean # Children/Household: 0.85

Type of Local Water Sources Used by Villagers: For drinking people mostly use the filter and water from the 1 standpipe that is municipally treated water. Household shallow tube wells and ponds are used for non-drinking purposes

Installation

Date: 2009

Duration: 3-4 weeks to build

Process: Locations chosen by IITB as these systems were initially trials so they requested permission from the local *Panchayat.* The land is owned by a local mens club who look after it.
Location: Near the center of town, along the main road
Cost: 80,000 Rupees (~$1,300 USD) max

Operation

[As] in Raw Water: 20-40 ppb
[As] in Treated Water: <10 ppb
Flow Rate: ~2 minute delay from pumping to flow out the tap (<100L/hr)
Vol of Treated Water Produced/Day: ~1500 L/day
Daily Treatment Time: Treatment done 'to-order' by each individual pumping what they need
Daily Operation Procedure: User pumps for a few mins, waits, then fills container from tap on tank
Reoccurring Costs: ~1200 R (~$20 USD) / year for iron nails and hand pump repair; Some families donate 10-25 R ($0.17-0.42 USD) / month for maintenance costs
Details on Operator(s): The club that own the land officially oversee the operation and maintenance
Maintenance Procedure: Men from the club volunteer to wash nails once every month and clean the first tank up to a depth of 40 cm from the top once /3-4 months
Maintenance Schedule: Takes approx. 3 hours to complete washing of tanks, rocks and nails
Operator Training: Club members were trained directly by Mr Ghosh
Frequency of Arsenic Testing: Unknown
Arsenic Test Results Posted Publicly: No
Visual Public Notice: "Arsenic Removal Unit designed & installed by IIT Bombay India 2009; Funded by Dept of Science & Technology, Govt of India" in English with no contact information or explanation of how the system works.

Waste

Volume: Arsenic-rich sludge dried = 35 kg/year
Type: Arsenic-rich sludge and precipitate from nails
Disposal Location(s): Dumped into a hole that was dug <1m deep beside the filter
Disposal Cost: Free (dumped)

Feedback/Notes

Accountability: Club members are elected and filter committee is formed through this group who also keep account of the money donated and used for maintenance, so in principle there should be accountability
Corruption: Families asked to 'donate' variable amounts of money for the filter and some people complained about this being too much money per month
Satisfaction: Some complaints about the distance to the filter from their homes
Awareness: Confusion between arsenic and iron
Level of understanding: None of the club members seemed interested in understanding the mechanics
Reliability/Durability: The system has only required small repairs and has never been offline since its instalment (except during cleaning)

Photos: IITB 2:3 and the area behind the filter where waste is dumped.

BESU

Scale: Community (100-500 families)
# of Units Visited: 3
As Removal Mechanism: Regenerable adsorbent – activated alumina *HAIX media
Pump: Submersible pumps used but not required
Construction Materials: Cylindrical stainless steel tank mounted above a well-head; metal pipes with metal tap(s) and often protected within a building or cage (built after by villagers) and several 2500 - 4000 L storage tanks
Estimated Lifespan: Adsorbent needs replacing/ regeneration annually

Village Code: BESU 3:1 — **Visited on: July 31, 2012**

Background
Village Name: Sakti Sadhana Club, Ashoknagar Town
Location: North 24 Paraganas, West Bengal, India
GPS: N22°50.503’ E 088°37.402’
Religion: Hindu
Total Households in Community: ~500 but surveyed nearest 100-150 households to the filter
Total Household Surveyed: 39
Mean Household Income for Village: 18,240 Rupees (~$304 USD) /month
Mean # People/Household: 4.51
Mean # Children/Household: 0.51
Type of Local Water Sources Used by Villagers: Villagers have a choice between paying for the filter water and using municipal standpipes for drinking, and household tube wells for non-drinking purposes.

Installation
Date: 2011
Duration: Several months to install in its entirety
Process: Club requested it to be installed after seeing others in the area. Local gov’t donated the land to the club. The club organised fundraising to pay 25% the initial capital costs and 75% paid for through the Tagore Foundation (NGO)
Location: Near the center of town in the main football field beside the club house
Cost: 300,000 Rupees (~$5,000 USD) for full system and building

Operation
[As] in Raw Water: >100 ppb
[As] in Treated Water: <10 ppb
Flow Rate: ~No delay to tap because water is treated and kept in the storage tank. Flow from tap is ~200 L/hr but there are 3 that can be used simultaneously
Vol of Treated Water Produced/Day: ~2500 L/day
Daily Treatment Time: Pumping into 4000L raw tank on the roof of the building takes 3 hours of pumping and then its gravity fed into the system. There are a few minutes delay at first, as the water runs through the system but throughout the day treatment is constant so there is no delay
Daily Operation Procedure: Operator pumps to fill up the top storage tank and
Reoccurring Costs: 500-750 R (~$7-11 USD) / month electricity plus repairs; Operator’s salary of 1500 R ($25 USD) /month; Families pay 30 R ($0.50 USD) /month for 20L of treated water/day plus a one-time membership fee to the club of 70 R ($1.17 USD); Delivery sold privately at 100-120 R ($1.67- 2 USD) /month depending on the distance
Details on Operator(s): Local man chosen by the water committee that was formed within the men’s club who is paid a monthly salary (relatively low compared to area’s mean)
Maintenance Procedure: Daily backwash of the system and yearly replacement of the HAIX media
Operator Training: Trained by BESU during installation briefly (~2 hours)
Frequency of Arsenic Testing: Once every 3 months
Arsenic Test Results Posted Publicly: Yes but results are in English

Visual Public Notice: In English and Bengla, clearly describe problem and system's designers and affiliations but without any contact information

Waste

Volume: Arsenic-rich liquid waste from regeneration process is 1600 kg

Type: Arsenic-rich adsorbent and relatively less arsenic-bearing backwash

Disposal Location(s): Backwash is dumped into a hold dug beside the filter that is filled with rocks; Adsorbent is brought to central location to be regenerated and solid sludge is buried there

Disposal Cost: New adsorbent: 18,000R ($300 USD); Regeneration: 10,000R ($167USD)

Feedback/Notes

Accountability: Operator is paid and help accountable to the water committee

Corruption: No complaints or suggestions of corruption

Satisfaction: People who cannot afford delivery complain about having to walk to the filter;

Awareness: Variable awareness in community about the local As problem and phys effects

Level of understanding: Operator aware of how system works mechanically, not chemically

Reliability/Durability: The system has only required small repairs and has never been offline since its instalment (except during cleaning)

Trust: People trust the Tagore Foundation who helped fund the initial costs, so therefore trust the system



Photos: Small delivery truck parked beside the building that houses the BESU 3:1 filter. The middle filter photo is of the filter from the inside of the building, and the backwash exits out the hoses through the brick wall to a brick-lined hole beside the building.

Village Code: BESU 3:2

Visited on: August 1, 2012

Background

Village Name: Nabarum Sangha Club, Ashoknagar (near Habra)

Location: North 24 Paraganas, West Bengal, India

GPS: N22°50.511' E 088°37.414'

Religion: Hindu

Total Households in Community: ~100

Total Household Surveyed: 37

Mean Household Income for Village: 11,650 Rupees (~$194 USD) /month

Mean # People/Household: 4.26

Mean # Children/Household: 0.77

Type of Local Water Sources Used by Villagers: Villagers have a choice between paying for the filter water and using municipal standpipes for drinking (which people complain is full of iron and thus undrinkable), and use household shallow tube wells for non-drinking purposes.

Installation

Date: 2004

Duration: One month initially but there have been several upgrades since

Process: The club was approached by Besu/Tagore Foundation (NGO) because it was widely known that this area is highly contaminated.

Location: In the field beside the club house

Cost: 200,000 Rupees (~$3,300 USD) for full system and building but materials and installation labour was donated by BESU

Operation

[As] in Raw Water: >100 ppb
[As] in Treated Water: 20-40 ppb
Flow Rate: ~No delay to tap because water is treated and kept in the storage tank. Flow from tap is ~150 L/hr
Vol of Treated Water Produced/Day: ~2000 L/day
Daily Treatment Time: Pumping into 4000L raw tank on the roof of the building takes 3 hours of pumping and then its gravity fed into the system. There are a few minutes delay at first, as the water runs through the system but throughout the day treatment is constant so there is no delay
Daily Operation Procedure: Operator pumps to fill up the top storage tank and
Reoccurring Costs: 600 R (~$10 USD) / month electricity plus repairs; Operator's salary of 1000 R ($17 USD) /month; Families pay 20 R ($0.33 USD) /month for 20L of treated water/day plus a one-time membership fee to the club of 70 R ($1.17 USD); Delivery sold privately at 80-100 R ($1.33-1.67 USD) /month depending on the distance. Treasurer of water committee estimated that total operation costs are 7,500 R ($125 USD) /month with a profit of 1500 R ($25 USD) /month for future repairs/regeneration.
Details on Operator(s): Local man chosen by the water committee that was formed within the men's club who is paid a monthly salary (relatively low compared to area's mean)
Maintenance Procedure: Daily backwash of the system and yearly replacement of the HAIX media
Operator Training: Trained by BESU during installation briefly (~2 hours)
Frequency of Arsenic Testing: Once per months
Arsenic Test Results Posted Publicly: Yes but results are in English
Visual Public Notice: In English and Bengla, clearly describe problem and system's designers and affiliations but without any contact information

Waste

Volume: Arsenic-rich liquid waste from regeneration process is 1600 kg
Type: Arsenic-rich adsorbent and relatively less arsenic-bearing backwash

Disposal Location(s): Backwash is dumped onto the grass of the adjacent field or into the pond that is 30m away from the filter; Adsorbent is brought to central location to be regenerated and solid sludge is buried there
Disposal Cost: New adsorbent: 18,000R ($300 USD); Regeneration: 10,000R ($167 USD)

Feedback/Notes

Accountability: One villager said that there are still high amounts of iron in the treated water which shows that the operator is not doing his job properly and this not being monitored properly by the committee.
Corruption: The area immediately behind the filter is very poor and most of those people (within walking distance) say they cannot afford to buy the filter water so it is delivered to families further away that can afford it; Several people also think that the club mixes 'chemicals/medicine' into the water but say that they don't.
Satisfaction: Several villagers feel they should not have to pay for the water, that its morally wrong
Awareness: General awareness in community about the local arsenic problem and phys effects
Level of understanding: Operator aware of how system works mechanically, not chemically
Reliability/Durability: The system has only required small repairs and has never been offline since its instalment (except during cleaning and upgrading of system)

 

Photos: BESU 3:2 from the outside and inside.

Village Code: BESU 3:3

Visited on: August 2, 2012

Background

Village Name: Binimay *Para*, Ashoknagar (near Habra)
Location: North 24 Paraganas, West Bengal, India
GPS: N22°50.942’ E 088°37.057’
Religion: Hindu
Total Households in Community: ~100
Total Household Surveyed: 36
Mean Household Income for Village: 7,279 Rupees (~$121 USD) /month
Mean # People/Household: 4.03
Mean # Children/Household: 0.41
Type of Local Water Sources Used by Villagers: Villagers have a choice between paying for the filter water and using municipal standpipes for drinking; Household shallow tube wells are used for non-drinking purposes.

Installation

Date: 2004?
Duration: 5-6 weeks to install the system and construct the building
Process: Besu/Tagore Foundation approached the *Panchayat* who formed a water committee to oversee the operation however it was dissolved soon after.
Location: Near the main road used to exit the semi-isolated community
Cost: 100,000 Rupees (~$1,667USD) for full system and building

Operation

[As] in Raw Water: >200 ppb
[As] in Treated Water: 20-40 ppb
Flow Rate: ~No delay to tap because water is treated and kept in the storage tank. Flow from tap is ~100 L/hr
Vol of Treated Water Produced/Day: <1000 L/day
Daily Treatment Time: Pumping into 2500L raw tank on the roof of the building takes 2 hours of pumping and then its gravity fed into the system. There are a few minutes delay at first, as the water runs through the system but throughout the day treatment is constant so there is no delay
Daily Operation Procedure: Operator pumps to fill up the top storage tank and
Reoccurring Costs: 300 R (~$5 USD) / month electricity plus repairs; Operator’s salary of 1000R ($17 USD) /month; Families pay 15 R ($0.25 USD) /month for 20L of treated water/day
Details on Operator(s): Local man volunteered but because not many people use this filter he often doesn’t make any salary so doesn’t feel the need to operate it every day

Maintenance Procedure: Daily backwash of the system and yearly replacement of adsorbent media
Operator Training: Trained by BESU during installation briefly (~1 hours)
Frequency of Arsenic Testing: Unknown (never?)
Arsenic Test Results Posted Publicly: No
Visual Public Notice: No notice

Waste
Volume: Arsenic-rich liquid waste from regeneration process is 1600 kg
Type: Arsenic-rich adsorbent and relatively less arsenic-bearing backwash

Disposal Location(s): Backwash is supposed to be dumped into a holding tank beside the filter that however villagers report that it is dumped into the adjacent pond; Adsorbent is supposed to be brought to central location to be regenerated and solid sludge is buried there however nobody remembers this actually occurring
Disposal Cost: New adsorbent: 18,000R ($300 USD); Regeneration: 10,000R ($167 USD)

Feedback/Notes
Accountability: There is no water committee or any form of accountability/over-seeing of the operator
Satisfaction: People generally very unhappy with having to pay since they “are so poor”
Awareness: Variable awareness in community about the local arsenic problem and phys effects
Level of understanding: Operator seems totally disinterested in the system and often sends his 10 year old son to operate it

Photos: BESU 3:3 from the outside and inside.

PalT/Harbr

Scale: Community (200-500 families)
# of Units Visited: 4
As Removal Mechanism: One-time use arsenic adsorbent – granular ferric hydroxide / AdsorpAs®
Pump: Submersible pumps used but not required
Construction Materials: Cylindrical stainless steel tanks connected well-head; metal pipes with metal tap(s) and often protected within a building or cage and and several 2500 - 4000 L storage tanks
Estimated Lifespan: Adsorbent last 12-18 months before it needs replacing

Village Code: PalT 4:1 **Visited on: August 8, 2012**

Background
Village Name: Harunghata Hospital, Harin Ghata
Location: Nadia, West Bengal, India
GPS: N22°56.748’ E 088°32.520’

Religion: Hindu
Total Households in Community: ~150
Total Household Surveyed: 39
Mean Household Income for Village: 8590 Rupees (~$143 USD) /month
Mean # People/Household: 4.28
Mean # Children/Household: 1.0
Type of Local Water Sources Used by Villagers: Villagers have a choice between paying for the filter water or using household shallow tube wells

Installation

Date: 2011
Duration: 2-3 months
Process: Funded through the Government of West Bengal, contracted to install hundreds of systems; Partnered with an NGO called Sajil Dhara in this case who approached the hospital directly.
Location: Beside the hospital along the main road
Cost: 300,000 Rupees (~$5,000 USD) for full system and building

Operation

[As] in Raw Water: <10 ppb
[As] in Treated Water: Below detectable limit
Flow Rate: ~No delay to tap because water is treated and kept in the storage tank. Flow from tap is ~200 L/hr but there are 2 that can be used simultaneously
Vol of Treated Water Produced/Day: ~3,000 L/day
Daily Treatment Time: Pumping into 3,000L raw tank on the roof of the building takes 3 hours of pumping and then its gravity fed into the system into the treated water storage tank and then out to the user
Daily Operation Procedure: System backwash which takes 15 minutes /day and then pumping of raw water into the top storage tank is on-going throughout the day

Reoccurring Costs: 1,200 R (~$20 USD) /month electricity plus repairs; Operator's salary of 600R ($10 USD) /month; Families pay 0.2R ($0.003 USD) /L
Details on Operator(s): Operator is woman who was chosen by the hospital board (her salary approx. half of that of male operator's)
Maintenance Procedure: Daily backwash and yearly replacement of the adsorption media
Operator Training: Trained by Sajil Dhara NGO
Frequency of Arsenic Testing: Unknown
Arsenic Test Results Posted Publicly: No
Visual Public Notice: In English and Bengla, name of company but without any contact information (of the company or NGO)

Waste

Volume: 10-20L of backwash per day; approx. 200L of spent adsorbent /year
Type: Arsenic-rich adsorbent and relatively less arsenic-bearing backwash

Disposal Location(s): Backwash is dumped onto the grass beside the filter and spent adsorbent dumped openly anywhere
Disposal Cost: New adsorbent: 22,000R ($367 USD)

Feedback/Notes

Accountability: Operator is paid and held accountable to the hospital and NGO that oversee the operation of the system
Corruption: System generates a large profit but there is no transparency in accounts
Satisfaction: Local people very unhappy about the price and chose to drink untreated water instead
Awareness: Community generally aware that there is a problem with the water but aren't totally clear on what arsenic is or the physical effects of arsenic on the body.
Level of understanding: Operator aware of how system works mechanically, but not open to talk about it
Reliability/Durability: Never offline since it was installed
Trust: Accounts record and villagers given written receipt of daily water purchase.

Photos: PalT 4:1 from the outside and the operator

Village Code: PalT 4:2 **Visited on: September 9, 2012**

Background

Village Name:	Srimanta *para*
Location:	Murshidabad, West Bengal, India
GPS:	N24°25.483' E 088°14.836'
Religion:	Hindu
Total Households in Community:	~100
Total Household Surveyed:	40
Mean Household Income for Village:	16,560 Rupees (~$276 USD) /month
Mean # People/Household:	5.08
Mean # Children/Household:	1.1
Type of Local Water Sources Used by Villagers:	Villagers have a choice between paying for the filter water or using household shallow tube wells or drinking from municipal stand pipes

Installation

Date:	2009
Duration:	> 1month
Process:	Funded through the Government of West Bengal, contracted to install hundreds of systems; Partnered with an NGO called Sajil Dhara in this case who approached the *Panchayat* directly and helped create a local water committee (all men) to oversee operation.
Location:	Beside the main road
Cost:	300,000 Rupees (~$5,000 USD) for full system and building

Operation

[As] in Raw Water:	20-40 ppb
[As] in Treated Water:	<10 ppb
Flow Rate:	~No delay to tap because water is treated and kept in the storage tank. Flow from tap is ~200 L/hr but there are 2 that can be used simultaneously
Vol of Treated Water Produced/Day:	~1,500 L/day
Daily Treatment Time:	Pumping into 3,000L raw tank on the roof of the building takes 3 hours of pumping and then its gravity fed into the system into the treated water storage tank and then out to the user
Daily Operation Procedure:	System backwash which takes 25 minutes /day and then pumping of raw water into the top storage tank is on-going throughout the day
Reoccurring Costs:	800 R (~$13 USD) /month electricity plus repairs; Operator's salary of 1,500R ($25 USD) /month; Families pay 20 R ($0.33 USD) /month for 15L daily (regardless of the size of family)

Details on Operator(s): Operator was chosen by the water committee, there was a formal application and interview process before he was hired
Maintenance Procedure: Daily backwash and yearly replacement of the adsorption media
Operator Training: Trained by Pal Trockner
Frequency of Arsenic Testing: Unknown
Arsenic Test Results Posted Publicly: No
Visual Public Notice: In Bengla, name of company with contact information and explanation of operation

Waste
Volume: 20-30L of backwash per day; approx. 200L of spent adsorbent /year
Type: Arsenic-rich adsorbent and relatively less arsenic-bearing backwash
Disposal Location(s): Backwash is dumped onto the grass beside the filter and spent adsorbent dumped openly anywhere
Disposal Cost: New adsorbent: 22,000R ($367 USD)/ 12-18 months

Feedback/Notes
Accountability: Operator is paid and held accountable by the water committee
Corruption: Accounts record and villagers given written receipt of daily water purchase;
Satisfaction: Located on the edge of the road on one side of the village and people who live on the other side think it is too far to walk (~800 m); 15L isn't enough per day for families with large number of people
Awareness: Community generally aware that there is a problem with the water but aren't totally clear on what arsenic is or the physical effects of arsenic on the body
Reliability/Durability: Never offline since it was installed
Trust: The operator was asked for proof of testing or certification for the filtration process which he couldn't give so they don't believe it is safe



Photos: PalT 4:2 and a close-up of the Bangla sign which displays the opening hours and price.

Village Code: Harb 5:1

Visited on: August 29, 2012

Background
Village Name: Block District Office in Phulia
Location: Nadia, West Bengal, India
GPS: N23°14.041’ E 088°29.748’
Religion: Hindu
Total Households in Community: ~500
Total Household Surveyed: 36
Mean Household Income for Village: 12,300 Rupees (~$205 USD) /month
Mean # People/Household: 4.19
Mean # Children/Household: 0.72
Type of Local Water Sources Used by Villagers: Villagers have a choice between paying for the filter water or using household shallow tube wells. There are also a few municipal stand pipes throughout the village (have high iron content)

Installation
Date: 2011
Duration: 4-5 weeks

Process: Funded through the Government of West Bengal, contracted to install hundreds of systems. No villagers/stakeholders consulted
Location: Beside the Block District Office building (Government office) near a traffic circle in the centre of town
Cost: 330,000 Rupees (~$5,500 USD) for full system and building

Operation

[As] in Raw Water: <10 ppb
[As] in Treated Water: Below detectable limit
Flow Rate: ~No delay to tap because water is treated and kept in the storage tank. Flow from tap is ~800 L/hr and there are 2 that can be used simultaneously
Vol of Treated Water Produced/Day: ~10,000-12,000 L/day
Daily Treatment Time: Pumping into 3,000L raw tank on the roof of the building takes 1 hour of pumping and then its gravity fed into the system into the treated water storage tank and then out to the user
Daily Operation Procedure: System backwash which takes 15 minutes twice /month and then pumping of raw water into the top storage tank is on-going throughout the day
Reoccurring Costs: 1,000 R (~$17 USD) /month electricity plus repairs; Operator's salary of 1,000 R ($17 USD) /month; Families pay 0.4R ($0.007 USD) /L
Details on Operator(s): Operator was hired by government office
Maintenance Procedure: Daily backwash and yearly replacement of the adsorption media
Operator Training: Trained by Harbauer
Frequency of Arsenic Testing: Unknown
Arsenic Test Results Posted Publicly: No
Visual Public Notice: In English and Bengla, name of company but without any contact information (of the company or NGO)

Waste

Volume: 20L of backwash twice /month; approx. 200L of spent adsorbent /year
Type: Arsenic-rich adsorbent and relatively less arsenic-bearing backwash

Disposal Location(s): Backwash is poured into the drain which runs into the nearby pond, and spent adsorbent dumped openly anywhere
Disposal Cost: New adsorbent: 22,000R ($367 USD)

Feedback/Notes

Accountability: System has a water meter so though no receipt is given too each customer, the operator must hand in money based on the total amount of treated water produced each day.
Corruption: System generates a large profit (Approx 5,000 R/day) but there is no transparency in accounts, and is thus assumed it goes to someone in the government office next door
Satisfaction: People travel from as far as 5km away to purchase (caters to more wealthy villagers) and many complaints about the very high price
Reliability/Durability: Never offline since it was installed

Photos:Harb 5:1 and the sign that that describes who the sponsor and manufacturer are.

Village Code: Harb 5:2 **Visited on: August 30, 2012**

Background

Village Name: Baruipur
Location: S 24 Parganas West Bengal, India
GPS: N22°21.396’ E 088°25.457’
Religion: Muslim
Total Households in Community: ~100
Total Household Surveyed: 42
Mean Household Income for Village: 6,650 Rupees (~$111 USD) /month
Mean # People/Household: 4.69
Mean # Children/Household: 1.07
Type of Local Water Sources Used by Villagers: Villagers have a choice between paying for the filter water or using household shallow tube wells.

Installation

Date: 2010
Duration: Approx. 6 weeks
Process: Funded through the Government of West Bengal, contracted to install hundreds of systems. No villagers/stakeholders consulted, organised through *Panchayat.* No current active water committee exists.
Location: Beside the main road as you enter town (beside new bridge)
Cost: 400,000 Rupees (~$6,600 USD) for full system

Operation

[As] in Raw Water: Below detectable limit
[As] in Treated Water: Below detectable limit
Flow Rate: ~No delay to tap because water is treated and kept in the storage tank. Flow from tap is ~500 L/hr
Vol of Treated Water Produced/Day: ~2,000 L/day
Daily Treatment Time: Pumping into 4,000L raw tank on the roof of the building takes 2 hours of pumping and then its gravity fed into the system into the treated water storage tank and then out to the user
Daily Operation Procedure: System backwash which takes 15 daily and then pumping of raw water into the top storage tank is on-going throughout the day
Reoccurring Costs: 800 R (~$8 USD) /month electricity plus repairs; Operator’s salary of 1,400R ($23 USD) /month; Families pay 15R ($0.25 USD) /month for unlimited amount of litres use
Details on Operator(s): Operator was appointed by the *Panchayat*
Maintenance Procedure: Daily backwash and yearly replacement of the adsorption media
Operator Training: Trained by Harbauer
Frequency of Arsenic Testing: Unknown
Arsenic Test Results Posted Publicly: No
Visual Public Notice: In English and Bengla, name of company but without any contact information (of the company or NGO)

Waste

Volume: 20L of backwash twice /month; approx. 200L of spent adsorbent /year
Type: Arsenic-rich adsorbent and relatively less arsenic-bearing backwash
Disposal Location(s): Backwash is poured into ground behind the filter (which connects to the local pond), and spent adsorbent dumped openly anywhere
Disposal Cost: New adsorbent: 22,000R ($367 USD)

Feedback/Notes

Accountability: There doesn’t seem to be much accountability as there the villagers pay directly to operator who has no objective body or committee overseeing the operation/system
Satisfaction: Villagers not happy with the price. They think it’s far too expensive.
Reliability/Durability: Never offline since it was installed

Photos: Harbr 5:2 from the front and a close up of the sign which is the manufacturer info.

AIIH&PH

Scale: Community (100-250 families)
\# of Units Visited: 3
As Removal Mechanism: Chemical oxidation and coagulation using sodium hypochloride and aluminium sulphate
Pump: Hand
Construction Materials: Metal tanks, pipes, metal tap(s) and plastic buckets and tubing
Estimated Lifespan: Months-Years (because of needed on-going chemical replacement)

Village Code: AIIH&PH 6:1

Visited on: September 6, 2012

Background
Village Name: Kouri *para*, Bahadurpur GP
Location: Murshidabad, West Bengal, India
GPS: N24°25.371’ E 088°13.737’
Religion: Hindu
Total Households in Community: ~100
Total Household Surveyed: 39
Mean Household Income for Village: 5,525 Rupees (~$92 USD) /month
Mean # People/Household: 5.78
Mean # Children/Household: 1.68
Type of Local Water Sources Used by Villagers: Mostly using household/public shallow tube wells for drinking

Installation
Date: 2010
Duration: < 1 month
Process: Funded through the Government of India. AIIH&PH worked with West Bengal Volunteer Health Association (WBVHA-Lalgola), to locate arsenic affected areas. The local Panchayat was contacted about finding land to donate and about forming a local water committee.
Location: Along the ring road that goes through the village
Cost: 105,000 Rupees (~$1,750 USD) for full system

Operation
[As] in Raw Water: 20-40 ppb
[As] in Treated Water: <10 ppb
Flow Rate: Hand pump needs to be pumped for 5-10 minutes first (40 pumps to fill 500ml bottle), then the flow from tap is ~200 L/hr

Vol of Treated Water Produced/Day: ~1,000 L/day
Daily Treatment Time: On-going, treatment is done to-order as there is no holding tank for treated water. Flow through the system takes several minutes
Daily Operation Procedure: Ensures the buckets on the top have proper chemicals in them and pump
Reoccurring Costs: Operator's salary is dependent on how many people decide to pay; Families are asked to pay 10 R ($0.17 USD) /month, but very few do
Details on Operator(s): Operator is the owner of the land
Maintenance Procedure: Backwash which takes 15 minutes /day and empty flocculent catchment tank.
Operator Training: Trained by AIIH&PH and WBVHA in one session
Frequency of Arsenic Testing: None (supposed to be but isn't tested)
Arsenic Test Results Posted Publicly: No
Visual Public Notice: Description of how the system works, names of all affiliations are in English without any contact information. Phone number of the manufacturer of the equipment is posted publically.

Waste
Volume: 10L of backwash per day; ~1.5kg of dry arsenic-rich sludge /month
Type: Arsenic-rich flocculants relatively less arsenic-bearing backwash

Disposal Location(s): Backwash and flocculants are put into a pit near the filter
Disposal Cost: None

Feedback/Notes
Accountability: There is a water committee established
Satisfaction: "Cost is too high, so we don't use the filter"
Awareness: many people recognised that putting the waste into the pit is dangerous
Level of understanding: There were no chemicals in the buckets at all (possibly because so few people use the filter anymore)
Reliability/Durability: The hand pump is broken and the operator has called the plumber and Jadavpur Uni for help. They someone would come to fix it and nobody has come (it's been 18 months). As a consequence of the hand pump squirting water everywhere during pumping, the filter is difficult to use.
Trust: Villagers feel abandoned


Photos: AIIH&PH 6:1 form the side and a view from the top of the chemical bucket.

Village Code: AIIH&PH 6:2 **Visited on: September 7, 2012**

Background
Village Name: Malatipur *para*, Bilborapopra GP
Location: Murshidabad, West Bengal, India
GPS: N24°26.041' E 088°13.417'
Religion: Muslim
Total Households in Community: ~100
Total Household Surveyed: 27 (left village early due to several aggressive villagers)
Mean Household Income for Village: 6,825 Rupees (~$114 USD) /month
Mean # People/Household: 6.11
Mean # Children/Household: 1.44
Type of Local Water Sources Used by Villagers: Using household/public shallow tube wells for drinking

Installation
Date: 2009
Duration: < 1 month
Process: Funded through the Government of India. AIIH&PH worked with West Bengal Volunteer Health Association (WBVHA-Lalgola), to locate arsenic affected areas. The local Panchayat was contacted about finding land to donate and about forming a local water committee.
Location: Along the ring road that goes through the village
Cost: 105,000 Rupees (~$1,750 USD) for full system

Operation
[As] in Raw Water: 60-80 ppb
[As] in Treated Water: Filter broken – Not functioning so sampling was impossible
Flow Rate: Unknown
Vol of Treated Water Produced/Day: None , as it is broken, but normally around 2,000-3,000 L /day
Daily Treatment Time: On-going, treatment is done to-order as there is no holding tank for treated water. Flow through the system takes several minutes
Daily Operation Procedure: Ensured the buckets on the top have proper chemicals in them and pump (6-7 hours of pumping total to provide water for everyone, so many men are needed to take turns using the pump contantly
Reoccurring Costs: Buying the chemicals (unknown price). Was told by JU that they would return with free re-fills of chemicals but they never returned. Unsure as to where to buy them so have never been replaced.
Details on Operator(s): Operator is the owner of the land
Maintenance Procedure: Empty flocculent catchment tank daily. Tanks backwashed 1 time /month and takes 2 hours of washing
Operator Training: Trained by AIIH&PH-JU and WBVHA in one 2-2.5hour session
Frequency of Arsenic Testing: None (supposed to be but isn't tested)
Arsenic Test Results Posted Publicly: No
Visual Public Notice: Description of how the system works, names of all affiliations are in English without any contact information. Phone number of the manufacturer of the equipment is posted publically.

Waste
Volume: 10L of backwash per day; ~1.5kg of dry arsenic-rich sludge /month
Type: Arsenic-rich flocculants relatively less arsenic-bearing backwash

Disposal Location(s): Backwash and flocculants are put into a the field behind the filter
Disposal Cost: None

Feedback/Notes
Accountability: Panchayat chose the committee which has been dissolved for years
Satisfaction: Several villagers unhappy with the taste of the treated water. "Tasted of bleaching powder", "Tastes bad", "We didn't like the taste".
Reliability/Durability: The hand pump broken so a committee member travelled to JU to ask for help in person and they said that a plumber would come to help but hasn't.
Trust: Villagers feel frustrated.
Corruption: When the filter was working, the operator charged 10R/month for each family to use it. After some time he built an addition to his house which upset many neighbours because they didn't feel it was ethical that he was personally financially profiting from the sales of clean water. Many

feel it should be totally free. Some stopped using the filter even before it broke because of this situation and didn't want their money "to go into the pockets of the operator".

Photo: AIIH&PH 6:2

Village Code: AIIH&PH 6:3

Visited on: September 8, 2012

Background

Village Name: Jiagung
Location: Murshidabad, West Bengal, India
GPS: N24°16.234' E 088°16.024'
Religion: Muslim
Total Households in Community: ~100
Total Household Surveyed: 39
Mean Household Income for Village: 5,350 Rupees (~$89 USD) /month
Mean # People/Household: 6.05
Mean # Children/Household: 1.72
Type of Local Water Sources Used by Villagers: Mostly using household/public shallow tube wells for drinking

Installation

Date: 2012
Duration: 1 month to build and 1 month of waiting to get chemicals
Process: Funded through the Government of India. AIIH&PH worked with West Bengal Volunteer Health Association (WBVHA-Lalgola), to locate arsenic affected areas. The local Panchayat was contacted about finding land to donate and about forming a local water committee. WBVHA has held several information meetings with village about arsenic awareness
Location: Along the main road into the village
Cost: 105,000 Rupees (~$1,750 USD) for full system

Operation

[As] in Raw Water: 350 ppb
[As] in Treated Water: <10 ppb
Flow Rate: Hand pump needs to be pumped for several hours to have regular flow (~200L /hour)
Vol of Treated Water Produced/Day: ~1,500 L/day
Daily Treatment Time: On-going, treatment is done to-order as there is no holding tank for treated water. Flow through the system takes several minutes (delay)
Daily Operation Procedure: Ensures the buckets on the top have proper chemicals in them and pump
Reoccurring Costs: Operator's salary is 600 R ($10 USD) /month and all other money goes to repair costs; Families are asked to pay 10-15 R ($0.17-0.25 USD) /month
Details on Operator(s): Operator is the owner of the land
Maintenance Procedure: Backwash and empty flocculent catchment tank once every 3-4 months and takes approximately 8 hours

Operator Training: The husband, wife and children were all trained by WBVHA for 3 days
Frequency of Arsenic Testing: None (supposed to be but isn't tested)
Arsenic Test Results Posted Publicly: No
Visual Public Notice: Description of how the system works, names of all affiliations are in English without any contact information. Phone number of the manufacturer of the equipment is posted publically.

Waste
Volume: 100L backwash once every 3-4 months; ~25kg of dry arsenic-rich sludge /yr
Type: Arsenic-rich flocculants relatively less arsenic-bearing backwash
Disposal Location(s): Backwash and flocculants are put into a hole beside the filter

Feedback/Notes
Accountability: There is a water committee established.
Satisfaction: Villagers have a serious problem with the operator. "I never use the filter because I had a quarrel with the land owner." "We don't use the filter because we don't trust the person whose land the filter is on. They use the water for all purposes including bathing and when we try to take water they shout at us." We don't use the filter because the land owner is rude." "The man on whose land the filter is one doesn't let anyone use it."
Awareness: NGO held several (<5) village meetings about arsenic awareness but according to some villagers, "they still don't believe."
Trust: Some villagers are concerned that they have never seen the plant being cleaned. "Nobody ever maintains the filter." "We have never seen anyone clean it."



Photos: AIIH&PH 6:3 and the hole full of waste that is beside the filter.

CGCRI

Scale: Community (~100 families)
# of Units Visited: 3
As Removal Mechanism: Adsorption using unspecified colloidal media particles suspended in water
Pump: Submersible pump (2Kg/cm^2 pressure required for membrane operation)
Construction Materials: Metal tanks, pipes, metal tap(s) and plastic tubing
Estimated Lifespan: 10-15 years?

Village Code: CGCRI 7:1 **Visited on: September 14, 2012**

Background
Village Name: Nibedita pally, Barasat
Location: North 24 Parganas, West Bengal, India
GPS: N22°44.134' E 088°29.602'
Religion: Hindu
Total Households in Community: ~100

Total Household Surveyed: 43
Mean Household Income for Village: 6,465 Rupees (~$108 USD) /month
Mean # People/Household: 4.33
Mean # Children/Household: 1.02
Type of Local Water Sources Used by Villagers: Mostly using household shallow tube wells or municipal standpipes for drinking

Installation

Date: 2003
Duration: < 1 week
Process: Funded through the Public Health Engineering Directorate (PHED) Govt. of West Bengal. A local man was contacted about operating the system because is family with someone from the government, so he donated the land and was encouraged to use this as a business opportunity (selling water).
Location: In the center of the village on the edge of a man's yard
Cost: 400,000 Rupees (~$6,667 USD) for full system

Operation

[As] in Raw Water: Below the Detectable Limit
[As] in Treated Water: Broken
Flow Rate: Broken
Vol of Treated Water Produced/Day: 2,500 L/day (if working)
Daily Treatment Time: On-going, treatment is done to-order as there is no holding tank for treated water. Flow through the system takes several minutes
Daily Operation Procedure: Adds media and mixes for 1 hour then waits 12 hours for oxidation to occur and then filtration through the membrane can occur.
Reoccurring Costs: Replacement of adsorbent media, operator's wage is paid with profits (if there are any), electricity which is approximately 1,000 R ($17 USD)/ month
Details on Operator(s): Operator is the owner of the land who seems very defensive with his answers and goes back to change previous answers in the interview. (Untrustworthy source?)
Maintenance Procedure: Daily backwashing, washing of membrane and removal of arsenic-rich sediments from feeder tank once every few months
Operator Training: Trained by CGCRI in one session
Frequency of Arsenic Testing: None (supposed to be but isn't tested)
Arsenic Test Results Posted Publicly: No
Visual Public Notice: None

Waste

Volume: 150L of liquid arsenic-rich sludge /month
Type: Arsenic-rich flocculants
Disposal Location(s): Backwash is dumped beside the filter and flocculants are put into a barrel and given back to CGCRI

Feedback/Notes

Accountability: The filter is run as a household business so there is no village input to how it is run
Satisfaction: Many people said the water costed too much and didn't use it because of that/
Awareness: many people recognised that putting the waste into the pit is dangerous
Reliability/Durability: Broken for 5-6 years and the operator hasn't bothered to get it fixed.
Trust: "We didn't use the filter because it was not well-maintained". Note: Owner/operator would not let me take ANY photo's of the system and because it is on his property I couldn't due to privacy request.

Not given permission to take photos of CGCRI 7:1 as it sits on private property.

Village Code: CGCRI 7:2 **Visited on: September 15, 2012**

Background

Village Name: Akrampur Talikhola, Barasat
Location: North 24 Parganas, West Bengal, India
GPS: N22°44.061' E 088°28.169'
Religion: Hindu/Muslim mixed
Total Households in Community: ~100
Total Household Surveyed: 25

Mean Household Income for Village: 4,875 Rupees (~$81 USD) /month

Mean # People/Household: 4.52

Mean # Children/Household: 1.16

Installation

Date: 2001

Duration: < 1 month

Process: Funded through the Public Health Engineering Directorate (PHED) Govt. of West Bengal. A local family was contacted about operating the system through the *Panchayat*, so they donated the land and was encouraged to use this as a business opportunity (selling water).

Location: Near the center of the village, behind their house

Cost: 450,000 Rupees (~$7,500 USD) for full system

Operation

[As] in Raw Water: 100 ppb

[As] in Treated Water: <10 ppb

Flow Rate: Flow rate from the membrane is <100 L/hr however they fill a holding tank with a tap that flows much faster

Vol of Treated Water Produced/Day: 500 L/day

Daily Treatment Time: 5-6 hours to fill the 500 L holding tank

Daily Operation Procedure: Adds media and mixes for 1 hour then waits 12 hours for oxidation to occur and then filtration through the membrane can occur.

Reoccurring Costs: Replacement of adsorbent media (500 ml/ 10,000 L of water), electricity which is approximately 900 R ($15 USD) /month; Users charged 0.5 R/L

Details on Operator(s): Operator is the family's oldest son

Maintenance Procedure: Backwashing of system, washing of membrane with water and a brush, and removal of arsenic-rich sediments from feeder tank every 3-4 months.

Operator Training: Trained by CGCRI irregularly over 3-4 months

Frequency of Arsenic Testing: None (supposed to be but isn't tested)

Arsenic Test Results Posted Publicly: No

Visual Public Notice: One sign in English stating the funding body and designer but without contact information (see photo below)

Waste

Volume: 40L of dry arsenic-rich sludge /year

Type: Arsenic-rich flocculants

Disposal Location(s): Backwash is dumped beside the filter and flocculants are put into a barrel and given back to CGCRI

Disposal Cost: None

Feedback/Notes

Accountability: The filter is run as a household business so there is no village input to how it is run

Satisfaction: Many people said the water costed too much and didn't use it because of that

Reliability/Durability: The filter has been broken for 5-6 years and the operator hasn't bothered to get it fixed. Trust: "We didn't use the filter because it was not well-maintained"

Photo: CGCRI 7:2

Village Code: CGCRI 7:3 **Visited on: September 16, 2012**

Background

Village Name: Akrampur *para*, Barasat
Location: North 24 Parganas, West Bengal, India
GPS: N22°43.960' E 088°28.263'
Religion: Muslim
Total Households in Community: ~100
Total Household Surveyed: 37
Mean Household Income for Village: 7,121 Rupees (~$118 USD) /month
Mean # People/Household: 4.65
Mean # Children/Household: 0.57
Type of Water Sources Used by Villagers: using municipal standpipes or household shallow tube wells

Installation

Date: 2003
Duration: 2 weeks
Location: Near the center of the village, along the main road
Cost: 200,000 Rupees (~$3,333 USD) for full system

Operation

[As] in Raw Water: 60-80 ppb
[As] in Treated Water: <10 ppb
Flow Rate: Flow rate from the membrane is <100 L/hr however they fill a holding tank with a tap that flows much faster
Vol of Treated Water Produced/Day: 500 L/day
Daily Treatment Time: 3 hours to fill the 2,500 L holding tank
Daily Operation Procedure: Adds media and mixes for 1 hour then waits 12 hours for oxidation to occur and then filtration through the membrane can occur.
Reoccurring Costs: Replacement of adsorbent media (500 ml/ 10,000 L of water), electricity which is approximately 1,200 R ($20 USD) /month; Users charged 1.0 R/L but includes free delivery
Details on Operator(s): Operator was hired by the land/system owner
Maintenance Procedure: Backwashing of system, washing of membrane with water and a brush, and removal of arsenic-rich sediments from feeder tank every 3-4 months.
Operator Training: Owner was trained by CGCRI in 1 day and operator trained in 1 hr by owner
Frequency of Arsenic Testing: None (supposed to be but isn't tested)
Arsenic Test Results Posted Publicly: No
Visual Public Notice: One sign in English stating the funding body and designer with phone number and email information (see photo below)

Waste

Volume: 20L of liquid arsenic-rich sludge /month
Type: Arsenic-rich flocculants
Disposal Location(s): Backwash and flocculants are dumped into the pond behind the filter

Feedback/Notes

Accountability: The filter is run as a household business so there is no village input to how it is run
Satisfaction: Many people said the water costed too much and didn't use it because of that.

Photos: CGCRI 7:3 and a photo of the sign.

Dug Wells

Scale: Community (~30-50 families)
# of Units Visited: 3
As Removal Mechanism: None required because this system uses surface water infiltration to shallow well and not the arsenic contaminated aquifer lower in the ground
Pump: Hand
Construction Materials: Cement rings, pvc pipe, netting, tin roof
Estimated Lifespan: Unknown

Village Code: Dug 8:1

Visited on: August 7, 2012

Background
Village Name: Faridkati *para*, Bishnupur Block
Location: North 24 Parganas, West Bengal, India
GPS: N22°54.506' E 088°47.465'
Well ID: PW 55
Religion: Hindu
Total Households in Community: <50
Total Household Surveyed: 35
Mean Household Income for Village: 3,994 Rupees (~$67 USD) /month
Mean # People/Household: 3.86
Mean # Children/Household: 0.80
Type of Local Water Sources Used by Villagers: Mostly using household shallow tube wells or the club's deep tube well for drinking and dug well water for cooking

Installation
Date: 2007
Duration: < 1 week
Process: Funded through private donations to Project Well and/or Aqua Welfare Society
Location: In the center of the village beside the main road
Cost: 42,000 Rupees (~$700 USD) for full system

Operation
[As] in Raw Water: 60-100ppb (tube well nearest to dug well)
[As] in Treated Water: <10ppb
Flow Rate: Attached directly to a hand pump so depends on speed of pumping
Vol of Treated Water Produced/Day: Unknown
Daily Treatment Time: None
Daily Operation Procedure: None (Hand pumping)
Reoccurring Costs: Replacement of bleaching agent is 180 R, ($3 USD) /year; Some households pay 10 R ($0.17 USD) /month to use but is mostly free; Field worker's salary is 1,500 R ($25 USD) / month but isn't the 'operator'
Details on Operator(s): Field worker is recruited locally (within village) to look after the Dug Well
Maintenance Procedure: Addition of Theoline (bleaching agent) once /week
Operator Training: Trained by Aqua Welfare Society's supervisor
Frequency of Arsenic Testing: Yearly testing
Arsenic Test Results Posted Publicly: No
Visual Public Notice: English sign posted; Bengla information pamphlets handed out by field workers regularly

Waste None.

Feedback/Notes
Accountability: Water committee is formed within each community to hold field worker accountable
Satisfaction: Water smells like pond water /jute so don't like drinking it;
Awareness: Mostly aware of arsenic problem (due to AWS campaign)
Reliability/Durability: Rumours that there are worms in the water

 

Photos: Dug 8:1 from the side and top

Village Code: Dug 8:2

Visited on: August 14, 2012

Background

Village Name: Naryanpur, Chakda Block
Location: Nadia, West Bengal, India
GPS: N23°01.132’ E 088°36.530’
Well ID: PW 177 & 157
Religion: Hindu
Total Households in Community: <50
Total Household Surveyed: 34
Mean Household Income for Village: 4,520 Rupees (~$75 USD) /month
Mean # People/Household: 5.03
Mean # Children/Household: 0.94
Type of Local Water Sources Used by Villagers: Mostly using household shallow tube wells or dug well water

Installation

Date: 2011
Duration: < 1 week
Process: Funded through private donations to Project Well and/or Aqua Welfare Society
Location: In the center of the village, along a road
Cost: 42,000 Rupees (~$700 USD) for full system

Operation

[As] in Raw Water: 50 ppb (tube well nearest to dug well)
[As] in Treated Water: Below Detectable Limit
Flow Rate: Attached directly to a hand pump so depends on speed of pumping
Vol of Treated Water Produced/Day: Unknown
Daily Treatment Time: None
Daily Operation Procedure: None (Hand pumping)
Reoccurring Costs: Replacement of bleaching agent is 180 R, ($3 USD) /year; Field worker’s salary is 1,500 R ($25 USD) / month
Details on Operator(s): Field worker is recruited locally (within village) to look after the Dug Well
Maintenance Procedure: Addition of Theoline (bleaching agent) once /week
Operator Training: Trained by Aqua Welfare Society’s supervisor
Frequency of Arsenic Testing: Annual testing
Arsenic Test Results Posted Publicly: No
Visual Public Notice: English sign posted; Bengla information pamphlets handed out by field workers regularly

Feedback/Notes

Accountability: Water committee is formed within each community to hold field worker accountable
Satisfaction: Still use the water even though it smells ‘muddy’
Awareness: Mostly aware of arsenic problem (due to AWS campaign)
Trust: Stopped using it when the latrine was constructed nearby.

Photos: Dug 8:2 being used by a local woman and the sign.

Village Code: Dug 8:3 **Visited on: August 15, 2012**

Background
Village Name: Pachim *para*, Dumuria, Chakda Block
Location: Nadia, West Bengal, India
GPS: N23°03.120’ E 088°37.200’
Well ID: PW 153 & 149
Religion: Hindu
Total Households in Community: <50
Total Household Surveyed: 30
Mean Household Income for Village: 4,050 Rupees (~$68 USD) /month
Mean # People/Household: 4.20
Mean # Children/Household: 0.90
Type of Local Water Sources Used by Villagers: Mostly using household shallow tube wells or dug well water

Installation
Date: 2010
Duration: < 1 week
Process: Funded through private donations to Project Well and/or Aqua Welfare Society
Location: In the center of the village, along a road
Cost: 42,000 Rupees (~$700 USD) for full system

Operation
[As] in Raw Water: Not tested
[As] in Treated Water: Below Detectable Limit
Flow Rate: Attached directly to a hand pump so depends on speed of pumping
Vol of Treated Water Produced/Day: Unknown
Daily Treatment Time: None
Daily Operation Procedure: None (Hand pumping)
Reoccurring Costs: Replacement of bleaching agent is 180 R, ($3 USD) /year; Field worker’s salary is 1,500 R ($25 USD) / month
Details on Operator(s): Field worker is recruited locally (within village) to look after the Dug Well
Maintenance Procedure: Addition of Theoline (bleaching agent) once /week
Operator Training: Trained by Aqua Welfare Society’s supervisor
Frequency of Arsenic Testing: Annual testing
Arsenic Test Results Posted Publicly: No
Visual Public Notice: English sign posted; Bengla information pamphlets handed out by field workers regularly

Feedback/Notes
Accountability: Water committee is formed within each community to hold field worker accountable

Satisfaction: "There is an odd smell to the water but we still use it because it's near to our house"
Awareness: Mostly aware of arsenic problem (due to AWS campaign).

Photo: Dug 8:3 in use.

SONO 45-25

Scale: Household (one per family)
# of Units Visited: 19 units in 1 village
As Removal Mechanism: Manufactured composite iron matrix (CIM) (one solid mass)
Pump: Hand
Construction Materials: Plastic buckets, brick chips, sand, wood charcoal, CIM
Estimated Lifespan: 2 years

Village Code: SONO 9:1 **Visited on: August 9, 2012**

Background
Village Name: Pauri *para* and Math *para* in Karola village
Location: North 24 Parganas, West Bengal, India
GPS: N22°55.074' E 088°46.044'
Religion: Hindu
Total Households in Community: 50-100
Total Household Surveyed: 36
Mean Household Income for Village: 5,370 Rupees (~$90 USD) /month
Mean # People/Household: 5.25
Mean # Children/Household: 1.20
Type of Local Water Sources Used by Villagers: Municipal stand pipes are almost exclusively used for drinking
Installation
Date: 2010
Duration: 1 hour to put together but very heavy to move and set-up
Process: Funded through an NGO called Behala Sambit who paid for the entire cost of the filters for each family. Approached by the Panchayat to help with the arsenic problem because as an NGO they were involved in the community for other reasons so the NGO fundraised and bought the filters for families who had someone that was affected by arsenicosis in their family.
Location: In each household
Cost: 2,500 Rupees (~$42 USD) for one system
Operation
[As] in Raw Water: 50ppb
[As] in Treated Water: Below Detectable Limit
Flow Rate: Advertised as 15 L/hr however when observed in the field, 5 L/hr was the actual mean flow rate
Vol of Treated Water Produced/Day: 57 L maximum per day for each system
Daily Treatment Time: 1-1.5 hours for 10 L (as advertised)

Daily Operation Procedure: Collection of raw water from a tube well. Pour water into the top bucket and allow for the water to sit for at least 15 minutes in the top bucket. Operator was open the flow from the top bucket to the lower bucket ensuring it is flowing at the correct rate to ensure proper contact time with the arsenic removal media.

Reoccurring Costs: None

Details on Operator(s): Operation is done by a member of each household, typically women

Maintenance Procedure: Recommendations by BETV-SAM include: Both buckets should be washed at least once per week with boiling water to prevent bacteriological contamination; The top bucket should always be filled with water and never left to dry out; Treated water should be tested immediately upon installation and every 6 months after that. None of these practices were witnessed in the village surveyed.

Operator Training: None

Frequency of Arsenic Testing: None

Arsenic Test Results Posted Publicly: No

Visual Public Notice: Printed on the side of the bucket: SONO Filter (patented) Approved by: BCSIR Gov't of Bangladesh (No chemical is added) Made in Bangladesh (Also written in Bengla with instructions however there is no contact information included))

Waste

Volume: 3 Kg of CIM per household

Type: CIM that is 'saturated' with arsenic, however TCLP (leeching tests) show it to be none hazardous when disposed up in a controlled landfill

Disposal Location(s): Landfill or open-dumping

Disposal Cost: None

Feedback/Notes

Accountability: No accountability, as it is up to every individual household to maintain the filter

Satisfaction: Very poor; Many people complained about how slow the flow rate is.

Awareness: The NGO who installed them did conduct an arsenic awareness campaign so most people were familiar with the concept

Reliability/Durability: 12/19 (63%) of systems observed were abandoned because they were broken. The tap often broke and in some cases the buckets were leaking.

Photo: SONO 45-25 9:1.

Nirmal

Scale: Household (one per family)
# of Units Visited: 15 units in Village 1; 28 units in Village 2; 21 units in Village 3
As Removal Mechanism: Activated Alumina (AA) (Same brand that BESU's 'Amal' uses)
Pump: Hand
Construction Materials: ferro cement body, rubber gasket, inner net, plastic valve, filter candle made of burned soil and rice husk
Estimated Lifespan: 1-2 years with regeneration of AA every 6 months

Village Code: Nirmal 10:1 **Visited on: August 9, 2012**

Background
Village Name: Pauri *para* and Math *para* in Karola village
Location: North 24 Parganas, West Bengal, India
GPS: N22°55.074' E 088°46.044'
Religion: Hindu
Total Households in Community: 50-100
Total Household Surveyed: 36
Mean Household Income for Village: 4,607 Rupees (~$77 USD) /month
Mean # People/Household: 5.19
Mean # Children/Household: 1.13
Type of Local Water Sources Used by Villagers: Municipal stand pipes are almost exclusively used for drinking

Installation
Date: 2010
Duration: 1 hour to put together but very heavy to move and set-up
Process: Funded through an NGO called *Behala Sambit* who paid for the entire cost of the filters for each family. Approached by the *Panchayat* to help with the arsenic problem because as an NGO they were involved in the community for other reasons so the NGO fundraised and bought the filters for families who had someone that was affected by arsenicosis in their family.
Location: In each household
Cost: 800 Rupees (~$13 USD) for one system

Operation
[As] in Raw Water: 20-40ppb
[As] in Treated Water: <10ppb
Flow Rate: 5-10 L/hr
Vol of Treated Water Produced/Day: 23-46 L/day
Daily Treatment Time: 2-4 hours depending on how much water is filtered
Daily Operation Procedure: Collection of raw water from a tube well. Pour water into the top chamber and allow for the water to seep through the candle. Water is gravity fed through the AA into the lower chamber. Flow of the treated water is controlled by the tap out the bottom.
Reoccurring Costs: 100 R ($1.7 USD) every 6 months for regeneration
Details on Operator(s): Operation is done by a member of each household, typically women
Maintenance Procedure: Inside of both chambers should be washed regularly with boiling water to prevent bacteriological contamination
Operator Training: None
Frequency of Arsenic Testing: None
Arsenic Test Results Posted Publicly: No
Visual Public Notice: No

Waste
Volume: Unknown
Type: Used activated alumina that is arsenic-rich
Disposal Location(s): Supposed to be regenerated and disposed of in a central location however this was not observed in practice. Households simply dumped the waste on the ground or into the drain
Disposal Cost: None

Feedback/Notes

Accountability: No accountability, as it is up to every individual household to maintain the filter
Satisfaction: Very poor; Many people complained about how slow the flow rate is.
Reliability/Durability: Many systems were abandoned because they were broken.

Photo: Nirmal 10:1 still in use.

Village Code: Nirmal 10:2 **Visited on: September 10, 2012**

Background
Village Name: Bhat *para*, Bhadnri Khamar
Location: Murshidabad, West Bengal, India
GPS: N23°54.866' E 088°12.869'
Religion: Muslim
Total Households in Community: 100-150
Total Household Surveyed: 34
Mean Household Income for Village: 2,845 Rupees (~$47 USD) /month
Mean # People/Household: 5.03
Mean # Children/Household: 1.35
Type of Local Water Sources Used by Villagers: Household shallow tubewells are used for drinking
Installation
Date: 2010
Duration: 1 hour to put together but very heavy to move and set-up
Process: *Panchayat* was given the filters to distribute to the lowest income families, but had total digression as to whom he gave them to
Location: In each household
Cost: 800 Rupees (~$13 USD) for one system
Operation
[As] in Raw Water: 100ppb
[As] in Treated Water: No sample available
Flow Rate: 5 L/hr
Vol of Treated Water Produced/Day: 20 L/day
Daily Treatment Time: 2-4 hours depending on how much water is filtered
Daily Operation Procedure: Collection of raw water from a tube well. Pour water into the top chamber and allow for the water to seep through the candle. Water is gravity fed through the AA into the lower chamber. Flow of the treated water is controlled by the tap out the bottom.
Reoccurring Costs: 100 R ($1.7 USD) every 6 months for regeneration
Details on Operator(s): Operation is done by a member of each household, typically women
Maintenance Procedure: Inside of both chambers should be washed regularly with boiling water to prevent bacteriological contamination
Operator Training: None
Frequency of Arsenic Testing: None
Arsenic Test Results Posted Publicly: No
Visual Public Notice: No

Disposal Location(s): Supposed to be regenerated and disposed of in a central location however this was not observed in practice. Households simply dumped the waste on the ground or into the drain
Disposal Cost: None

Feedback/Notes

Accountability: No accountability, as it is up to every individual household to maintain the filter
Satisfaction: Very poor; Many people complained about how slow the flow rate is.
Reliability/Durability: 25/28 systems were abandoned because they were broken.


Photo: Nirmal 10:2 discarded by side of the road and Nirmal 10.3 defunct and abandoned beside a hut.

Village Code: Nirmal 10:3

Visited on: September 11, 2012

Background

Village Name: Pin *para*, Bhadnri Khamar
Location: Murshidabad, West Bengal, India
GPS: N23°54.099' E 088°12.894'
Religion: Muslim
Total Households in Community: 100
Total Household Surveyed: 38
Mean Household Income for Village: 3,335 Rupees (~$55 USD) /month
Mean # People/Household: 6.05
Mean # Children/Household: 2.13
Type of Local Water Sources Used by Villagers: Household shallow tubewells are used for drinking

Installation

Date: 2010
Duration: 1 hour to put together but very heavy to move and set-up
Process: *Panchayat* was given the filters to distribute to the lowest income families, but had total digression as to whom he gave them to
Location: In each household
Cost: 800 Rupees (~$13 USD) for one system

Operation

[As] in Raw Water: 100ppb
[As] in Treated Water: No sample available
Flow Rate: 5 L/hr
Vol of Treated Water Produced/Day: 20 L/day
Daily Treatment Time: 2-4 hours depending on how much water is filtered
Daily Operation Procedure: Collection of raw water from a tube well. Pour water into the top chamber and allow for the water to seep through the candle. Water is gravity fed through the AA into the lower chamber. Flow of the treated water is controlled by the tap out the bottom.
Reoccurring Costs: 100 R ($1.67 USD) every 6 months for regeneration
Details on Operator(s): Operation is done by a member of each household, typically women

Maintenance Procedure: Inside of both chambers should be washed regularly with boiling water to prevent bacteriological contamination
Operator Training: None
Frequency of Arsenic Testing: None
Arsenic Test Results Posted Publicly: No

Waste

Volume: Unknown
Type: Used activated alumina that is arsenic-rich
Disposal Location(s): Supposed to be regenerated and disposed of in a central location however this was not observed in practice. Households simply dumped the waste on the ground or into the drain

Feedback/Notes

Accountability: No accountability, as it is up to every individual household to maintain the filter
Satisfaction: Very poor; Many people complained about how slow the flow rate is.
Reliability/Durability: 20/21 systems were abandoned because they were broken.

<u>DRDO</u>

Scale: Household (one per family)
# of Units Visited: 38 units in Village 1; 35 units in Village 2
As Removal Mechanism: ZVI ball made of recycled steel
Pump: Hand
Construction Materials: stainless steel body, fabric nets, local sand, manufactured adsorbent ball
Estimated Lifespan: 1-2 years with replacement of sand and ball every 6 months

Village Code: DRDO 11:1 — **Visited on: August 20, 2012**

Background

Village Name: Paschim *para*,
Location: Nadia, West Bengal, India
GPS: N23°12.443’ E 088°30.117’
Religion: Hindu
Total Households in Community: 50-100
Total Household Surveyed: 38
Mean Household Income for Village: 4,650 Rupees (~$78 USD) /month
Mean # People/Household: 4.32
Mean # Children/Household: 1.21
Type of Local Water Sources Used by Villagers: Municipal gov’t started to construct a deep tube well and water tower however abandoned the project. The deep tube though is being used by most of the village (illegally?). When tested for arsenic, this deep tube well showed concentrations of >50ppb of arsenic.

Installation

Date: 2010
Duration: <1 hour to put together
Process: Funded through the Gov’t of India but installed through an NGO called Save the Environment. The filter was sold to villagers at a subsidised cost of 100R
Location: In each household
Cost: 2,000 Rupees (~$33 USD) for one system

Operation

[As] in Raw Water: 50ppb
[As] in Treated Water: <10ppb
Flow Rate: 10 L/hr
Vol of Treated Water Produced/Day: 20-30 L/day
Daily Treatment Time: 2-3 hours depending on how much water is filtered
Daily Operation Procedure: Collection of raw water from a tube well. Pour water into the top chamber and allow for the water to seep through the three chambers. Water is gravity fed through and the flow of the treated water is controlled by the tap out the bottom.
Reoccurring Costs: 100 R ($1.7 USD) every 6 months for a new iron ball

Details on Operator(s): Operation is done by a member of each household, typically women
Maintenance Procedure: Inside the chambers should be washed regularly with boiling water to prevent bacteriological contamination
Operator Training: None
Frequency of Arsenic Testing: None
Arsenic Test Results Posted Publicly: No
Visual Public Notice: No

Waste

Volume: 1kg iron ball every six months
Type: Adsorbent ball and sand are arsenic-rich
Disposal Location(s): Supposed to be collected by the NGO and disposed of by having bricks made however villagers were told to burn or bury the ball and just dump the sand.

Feedback/Notes

Accountability: No accountability, as it is up to every individual household to maintain the filter
Satisfaction: Very poor; Many people complained about how slow the flow rate is.
Awareness: Very aware that the waste is toxic and of the problem because many people have died in this area due to arsenic related causes. Many people cautious of burning the waste (even though they were told to) so some have hung the iron balls up in trees so children can't touch them and so they don't contaminate the water more.
Reliability/Durability: Many systems were abandoned because they were broken.
Trust: Complete distrust for the NGO because the local representative inflates the price of the adsorbent and nets depending on the person buying it. He is the only person they know to buy it from so are forced to pay the higher price or stop using it.


Photo: DRDO 11:1

Photo: DRDO 11:2

Village Code: DRDO 11:2

Visited on: August 22, 2012

Background

Village Name: Lalmath *para*,
Location: Nadia, West Bengal, India
GPS: N23°12.273' E 088°30.320'
Religion: Hindu
Total Households in Community: 50-100
Total Household Surveyed: 35
Mean Household Income for Village: 5,630 Rupees (~$94 USD) /month
Mean # People/Household: 4.03
Mean # Children/Household: 0.83
Type of Local Water Sources Used by Villagers: Municipal gov't started to construct a deep tube well and water tower however abandoned the project. The deep tube

though is being used by most of the village (illegally?). When tested for arsenic, this deep tube well showed concentrations of >50ppb of arsenic.

Installation

Date:	2010
Duration:	<1 hour to put together
Process:	Funded through the Gov't of India but installed through an NGO called Save the Environment. The filter was sold to villagers at a subsidised cost of 100R
Location:	In each household
Cost:	2,000 Rupees (~$33 USD) for one system

Operation

[As] in Raw Water:	50ppb
[As] in Treated Water:	<10ppb
Flow Rate:	10 L/hr
Vol of Treated Water Produced/Day:	20-30 L/day
Daily Treatment Time:	2-3 hours depending on how much water is filtered
Daily Operation Procedure:	Collection of raw water from a tube well. Pour water into the top chamber and allow for the water to seep through the three chambers. Water is gravity fed through and the flow of the treated water is controlled by the tap out the bottom.
Reoccurring Costs:	100 R ($1.7 USD) every 6 months for a new iron ball
Details on Operator(s):	Operation is done by a member of each household, typically women
Maintenance Procedure:	Inside the chambers should be washed regularly with boiling water to prevent bacteriological contamination
Operator Training:	None
Frequency of Arsenic Testing:	None
Arsenic Test Results Posted Publicly:	No
Visual Public Notice:	No

Waste

Volume:	1kg iron ball every six months
Type:	Adsorbent ball and sand are arsenic-rich
Disposal Location(s):	Supposed to be collected by the NGO and disposed of by having bricks made however villagers were told to burn or bury the ball and just dump the sand. When washed the 'red' water was washed down the drain.

Feedback/Notes

Accountability: No accountability, as it is up to every individual household to maintain the filter

Satisfaction: Very poor; Many people complained about how slow the flow rate is.

Awareness: Very aware that the waste is toxic and of the problem because many people have died in this area due to arsenic related causes. Many people cautious of burning the waste (even though they were told to) so some have hung the iron balls up in trees so children can't touch them and so they don't contaminate the water more.

Reliability/Durability: Many systems were abandoned because they were broken.

Trust: Complete distrust for the NGO because the local representative inflates the price of the adsorbent and nets depending on the person buying it. He is the only person they know to buy it from so are forced to pay the higher price or stop using it.

Appendix II: English Field Survey

Section 1 **Informed Consent** Survey Code: __________

Namaste. My name is ______ and this is ______, we are surveyors hired by the University of Oxford in the UK. Here, please have a business card. We are helping conduct a study on clean-water technologies, like filters, rain water, tube wells, etc. The reason we would like to speak with you specifically is because we seek the opinions of residents in this area about the installation, use, maintenance, disposal and cost of the technology that you use. If you are willing to participate it would be in the form of answering some questions. The interview should take approximately 20-30 minutes. There are no benefits to participating in this study other than contributing to developing a broader understanding of sustainable clean-water technologies. If you choose to participate, we cannot offer any material compensation. If you choose to participate, the records of this research will be kept private. In any future publications, information that will make it possible to identify any participants will not be included. Research records will be kept in a locked file. If you do agree to participate, your participation is completely voluntary. We want to assure you that if you decide to not answer a particular question or wish to discontinue the interview all together at any point, then that is completely fine. Do you have any questions about what I have mentioned thus far? If you have any questions about the study in the future, please feel free to contact Tam, the Oxford researcher in charge of this program. All of her information is on the card we have given you.

1 Do you agree to participate? *(Circle)* No / Yes Start Time: __________ End Time: __________

Section 2 **Household Information**

2 How many people live in this household: _________ *(#)*

3 How old are they? What do they do for work? What is their education level?

Gender *(Circle)* Age *(#)* Occupation *(Write down)* Highest Education Level Completed (Circle one)
F/M _____ ________________None / Primary / Middle / High / College / Other____
F/M _____ ________________None / Primary / Middle / High / College / Other____
F/M _____ ________________None / Primary / Middle / High / College / Other ___
F/M _____ ________________None / Primary / Middle / High / College / Other____

Section 3 **Water Source and Use**

Fill in the table using C or P for current usage or past usage. Also add comments or any other relevant details into the comment section.

Current and Past Usage (C, P)	**River**	**Lake/ Pond**	**TubeWell**		***Rain**		***DugWell**		***Time**		***Filter**		**Other______ (buy bottled?)**	**Comments (Depth of tube Well, Contain arsenic? Type of filter)**
			Hh	Pb	Hh	Pb	Hh	Pb	Hh	Pb	Hh	Pb		
Drinking/cooking														
Bathing/hygiene														
Washing dishes/laundry														
Irrigating crops/gardening														
Livestock														

(C=Currently Use, P=Past Use, Hh=Household Scale/Privately Owned, Pb=Publicly Owned/Community Scale)
Clean Water Source (CWS)

Example questions used to fill out the above table:

4 Where do you get your water from? Is that used for drinking/cooking/washing?
In the past, where did your household get water from?
Do you use a filter? (Which model?) Why?
Have you ever used a filter in the past? (Which model?) Why did you stop?
Who owns the tube well(s)?
What is the depth of the tube well(s)? _________ *(Metres)*
Does the tube well have arsenic? *(Circle)* No / Unknown / Yes
How do you know? Has it been tested?

Section 4 Clean Water Source (CWS) used for Drinking/Cooking *(see highlighted boxes in above table)*

If no Clean Water Source has ever been used, check this box □ and skip to Section 5.

5 The next set of questions are going to focus on your household's past / present-day *(circle one)* use of the_*(insert CWS here)*_for drinking water. How long have / did you use(d) it for? _________ *(Months)*

6 Before you started using the __(insert CWS here)__ explain how you first learned about it
____
____
____

7 What were some of the main reasons your household decided to begin use? *(Circle all that apply)*
Affordable? Near to your home? Convinced by friends? Convinced by leaders? Other?___________

8 How long did it take to install the __(insert CWS here)__? _________ *(Hours or days or months)*

9 Who installed it? *(Circle all that apply)*
Members of your household / Community members / NGO / Government / University / Other______

10 Were the workers paid for their work? *(Circle)* No / Unknown / Yes
11 If yes, How much? _________ *(Rupees per hour or day or month)*

12 What was the cost of purchasing and installing the __(insert CWS here)__? _________ *(Rupees)*

13 How much did your household contribute to those costs? _________ *(Rupees)*

14 Do you pay a tariff to have access to this water? _________ *(Rupees per month)*

15 What is your average household income? _______________ *(Rupees per month)*

16 How far away from your house is the __(insert CWS here)__? _________ *(Meters or Minute's walk)*

17 How do you collect the water? *(Circle)* Walk / Cycle-power / Drive / It is Delivered / Other:________
18 If delivery, What is the cost? _________ *(Rupees per month)*
19 If walk/cycle/drive, Who in your household goes? *(Circle all that apply)* Female / Male, Adult / Child
20 Is this task physically *(Circle)* Difficult / Not Difficult / Easy for this person?

21 If a filter is used, how long does filtration take? _________ *(Minutes)*

22 Is there regularly a queue for water? *(Circle)* No / Unknown / Yes
23 If yes, on average how long must one have to wait in the queue to collect the water? _____*(Minutes)*

24 How many times a day does your household collect drinking water? _________ *(Number of times)*

25 Is any chemicals or medicine put in the water before you drink it? *(Circle)* No / Unknown / Yes
26 If yes, do you know which chemicals or medicine and/or the quantity? Explain________________

27 How would you describe the taste (smell) of the drinking water? *(Circle)*
Perfect / Good / Acceptable / Poor / Very Poor or Bad

28 How would you describe the colour of the drinking water? *(Circle)*
Perfectly Clear / Good / Neutral / Poor / Very Poor or Bad

29 Does anybody in your household do regular maintenance or testing on the __(insert CWS here)__?
(Circle) No / Unknown / Yes
30 If yes, How often is this done? _________ *(# per month)*
Who and were they trained? Explain____
31 How many hours did they spend in training? _________ *(Hours)*

32 Are they paid to do this work? *(Circle)* No / Unknown / Yes
33 If yes, What is their wage? _________ *(Rupees per month)*
How often is this done? _________ *(# per month)*
34 Do you trust that they are doing maintenance & testing regularly and properly?
(Circle) No / Unknown / Yes
How often do you…
35 Observe maintenance or testing being done? *(Circle)* Never / Rarely / Regularly / Often
36 Ask person about regular maintenance or testing? *(Circle)* Never / Rarely / Reg / Often
37 If no, Does somebody from outside the household do regular maintenance or testing on it?
(Circle) No / Unknown / Yes
38 If yes, Who, and were they trained? Explain_______________________________________
39 How many hours did they spend in training? _________ *(Hours)*
40 Is the worker paid to do this work? *(Circle)* No / Unknown / Yes
41 If yes, What is their wage? _________ *(Rupees per month)*
How often is this done? _________ *(# per month)*
42 Do you trust that they are doing maintenance & testing regularly and properly?
(Circle) No / Unknown / Yes
How often do you…
43 Observe maintenance or testing being done? *(Circle)* Never / Rarely / Regularly / Often
44 Ask worker about regular maintenance or testing? *(Circle)* Never / Rarely / Reg / Often
45 Ask worker's boss about regular maintenance or testing? *(Circle)* Never / Rare / Reg / Oft

46 Is waste produced by the __(insert CWS here)__? *(Circle)* No / Unknown / Yes
47 If yes, What is the volume of waste create? _________ *(Litres per day or month)*
48 What is the distance between where this waste is dumped and your home? ________ *(Meters)*
49 What is the cost of disposal? _________ *(Rupees per month)*

50 What is the life span of the __(insert CWS here)__? _________ *(Years)*

***Note: these questions were at the end of the survey but were only put here to save space in the appendix.**

Section 6 User's 'Willingness'

103 What is the maximum distance your household would be willing to walk for clean water? __*(Meters)*

104 What is the most ideal distance? ___________ *(Meters)*

105 What is the longest amount of time you are willing to wait to have water filtered (/ bucket)? __*(Min)*

106 What is the most ideal amount of time? ___________ *(Minutes)*

107 How many times per week would you be willing to do maintenance on a system? ___________ *(#)*

108 What is the maximum your household is willing to spend contributing to the initial cost of buying a system? ___________ *(Rupees)*

109 What is the most ideal amount? ___________ *(Rupees)*

110 What is the maximum your household is willing to spend per month on clean water? _____ *(Rupees)*

111 What is the most ideal amount? ___________ *(Rupees)*

Section 5 User's Values

These next questions are about clean water technologies/systems in general. The point is to identify how important or unimportant certain values and criterion are to you and your household. Please answer honestly.

How important is (it to you)… *(Circle most representative value)*

No.	Question	Very Unimportant	Unimportant	Neutral	Important	Very Important	
51	to be consulted before the installation process?	-2	-1	0	+1	+2	X
52	to actively participate in the decision-making process?	-2	-1	0	+1	+2	X
53	for someone in your household to participate in the decision?	-2	-1	0	+1	+2	X
54	if the system is designed in an environmentally friendly way?	-2	-1	0	+1	+2	X
55	the system's size or area?	-2	-1	0	+1	+2	X
56	the type of materials used in building the system?	-2	-1	0	+1	+2	X
57	the distance the system is from your house?	-2	-1	0	+1	+2	X
58	the rate (or speed) that the system produces clean water?	-2	-1	0	+1	+2	X
59	to understand the installation process?	-2	-1	0	+1	+2	X
60	that clean water is affordable?	-2	-1	0	+1	+2	X
61	that the system is reliable?	-2	-1	0	+1	+2	X
62	to be given several options when choosing a CWT?	-2	-1	0	+1	+2	X
63	that the quality of water is tested regularly?	-2	-1	0	+1	+2	X
64	to understand how the system operates?	-2	-1	0	+1	+2	X
65	if the cleaned water tastes slightly bad?	-2	-1	0	+1	+2	X
66	if the water smells odd?	-2	-1	0	+1	+2	X
67	to understand the maintenance procedures?	-2	-1	0	+1	+2	X
68	that the person doing the testing/maintenance is paid?	-2	-1	0	+1	+2	X
69	that the person doing the testing/maintenance is trained?	-2	-1	0	+1	+2	X
70	to have the ability to hold the maintenance person accountable?	-2	-1	0	+1	+2	X
71	that the system is installed as quickly as possible	-2	-1	0	+1	+2	X
72	that clean water is free?	-2	-1	0	+1	+2	X
73	that your household understands the physical effects of Arsenic in water?	-2	-1	0	+1	+2	X
74	if the maintenance person does not have a boss or supervisor?	-2	-1	0	+1	+2	X
75	if the cleaned water has a strong taste?	-2	-1	0	+1	+2	X
76	that the water is perfectly clear?	-2	-1	0	+1	+2	X
77	that the system is very near your house?	-2	-1	0	+1	+2	X
78	if you have to conduct small repairs on the system?	-2	-1	0	+1	+2	X
79	to know the arsenic concentration in the treated water?	-2	-1	0	+1	+2	X
80	the amount of waste or sludge generated by the system?	-2	-1	0	+1	+2	X
81	if waste or sludge is dumped near your house?	-2	-1	0	+1	+2	X
82	if waste or sludge is dumped near the water source?	-2	-1	0	+1	+2	X
83	if there is an aspect of recycling or regeneration in the system?	-2	-1	0	+1	+2	X
		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	
84	I prefer the size of the CWT to be as small as possible	-2	-1	0	+1	+2	X
85	I prefer the CWT be constructed with recycled materials	-2	-1	0	+1	+2	X
86	Trusting the system and those involved with it is important	-2	-1	0	+1	+2	X
87	Those who can afford to pay for water should pay a clean water tariff	-2	-1	0	+1	+2	X
88	I prefer having a personal CWT inside my home rather than using a comm system	-2	-1	0	+1	+2	X
89	All systems should have informative signs	-2	-1	0	+1	+2	X
90	I do not want to maintain my own water filter	-2	-1	0	+1	+2	X
91	Using chemicals or medicine to make water safe is bad and undesirable	-2	-1	0	+1	+2	X
92	I want to have access to all the financial details involving the system	-2	-1	0	+1	+2	X
93	Water should be free for everyone	-2	-1	0	+1	+2	X
94	I am willing to drink water with a slight taste as long as it's safe and clean	-2	-1	0	+1	+2	X
95	Having water delivered or piped to my home is the most ideal option	-2	-1	0	+1	+2	X
96	I feel that a CWT that uses power is not reliable	-2	-1	0	+1	+2	X
97	I do not care if a CWT creates Arsenic rich sludge or waste	-2	-1	0	+1	+2	X
98	I do not worry about where Arsenic rich sludge is dumped	-2	-1	0	+1	+2	X
99	Clean water should have no taste	-2	-1	0	+1	+2	X
100	I will only drink water that is clear in colour	-2	-1	0	+1	+2	X
101	I am willing to walk a short distance to get clean water	-2	-1	0	+1	+2	X
102	I would typically trust groups from outside my village who suggest CWT	-2	-1	0	+1	+2	X

Appendix II: Bangla Survey

সমীক্ষা -কাড : ____________________.

বিভাগ ১: **জানি-য় অনুমতি গ্রহণ**

নমস্কার, আমার নাম ____ , আর ইনি ____ । আমরা ইংল্যান্ডের অক্সফোর্ড বিশ্ববিদ্যালয়ের হয়ে কতকগুলো তথ্য সংগ্রহ করছি একটা সমীক্ষার জ-ন্য; অনুগ্রহ ক-র একটা কার্ড রাখুন। আমরা এই সমীক্ষাটা করছি জল দূষণমুক্ত করার বিভিন্ন প্রযুক্তির উপর, যেমন ফিল্টার, বৃষ্টির জল, এই সব। আমরা যে কারণে বিশেষ ভাবে আপনার সঙ্গে কথা বলতে চাইছি, তা হল আমরা এই এলাকার মানু-ষর কাছ -থ-ক জল পরিস্কার করার -য সব প্রযুক্তির তাঁরা ব্যবহার ক-রন, -সই প্রযুক্তির গুলির ব্যবহার, পরিচর্যা, পরিত্যাগ করার উপায় ও আর্থিক মূ-ল্যর বিষ-য় তাঁ-দর মতামত জান-ত চাইছি। আপনি যদি এই সমীক্ষা-ত অংশ নি-ত চান, তাহ-ল জানি-য় রাখি, এই সমীক্ষাটা হ-ব ক-থাপকথ-নর মাধ্য-ম। এই ক-থাপকথ-নর জ-ন্য সময় লাগ-ব ২০ -থ-ক ৩০ মিনিট। বৃহত্তর ক্ষেত্রে সম্যক ভাবে জল পরিস্কার করার বিভিন্ন প্রযুক্তিরর সম্বন্ধে বিষদে জ্ঞান লাভ ছাড়া এই সমীক্ষার অন্য কোন উপকারিতা -নই। আপনি যদি অংশগ্রহ-ণ আগ্রহি থা-কন, তাহ-ল আপনা-ক জানি-য় রাখি, আমরা আপনা-দর -কান রকম সাহায্য - বৈষিক বা আর্থিক - কর-ত পারব না। আপনি যদি অংশগ্রহ-ণ আগ্রহি থা-কন, তাহ-ল আপনা-ক জানি-য় রাখি, এই সমীক্ষার সমস্ত -রকর্ড -গাপন রাখা হ-ব। ভবিষ্য-ত যদি এই সমীক্ষার -কান অংশ -কাথাও ছাপা হয়, তাহ-ল অংশগ্রহণকারী-দর পরিচয় -গাপন রাখা হ-ব। এই সমীক্ষার সমস্ত নথি-পত্র বন্ধ একটা ফাইলের মধ্যে রাখা থাক-ব। আপনি যদি অংশগ্রহ-ণ আগ্রহি থা-কন, তাহ-ল তা সম্পূর্ণ -সচ্ছায়, আমরা -কান ভা-ব আপনা-ক -জারাজুরি করব না। আপনা-ক জানি-য় রাখি, আপনি যদি ক-য়কটা প্র-শ্নর পর আর উত্তর দিতে না চান সেটা সম্পূর্ণ আপনার ইচ্ছে, এবং আমরা তা সম্পূর্ণ রকম ভা-ব -ম-ন -নব। এই পর্যন্ত যা ব-লছি তা নিয়ে কি কোন প্রশ্ন আছে? ভবিষ্যতে যদি কোন প্রশ্ন থাকে, তাহলে অক্সফোর্ড বিশ্ববিদ্যালয়ের যে মেয়েটি - ট্যাম - এই সার্ভের দায়িত্ত্বে রয়েছে, তার সঙ্গে যোগাযোগ করতে পারেন; ওই কার্ডে ওঁর সমস্ত পরিচয় আছে।

আপনি কি অংশগ্রহ-ণ আগ্রহী? *(-গাল কর)* **হ্যাঁ / না** শুরুর সময়____________________ -শ-ষর সময়

বিভাগ ২: **গৃহস্থালি সম্বন্ধিত তথ্যাবলি**

১. এই গৃ-হ কতজন বাস ক-র? ________________________ *(#)*

২. তাঁ-দর বয়স কত? কি কাজ ক-রন? কতদুর -লখাপড়া ক-র-ছন?

৩. *লিঙ্গ* *(-গাল কর)*	*বয়স* *(#)*	*কাজ* *(-লখ)*	*স-র্বাচ্চ -লখাপড়ার স্তর* *(-গাল কর)*
স্ত্রী / পুঃ :	_____	________________________	শূণ্য / প্রাথমিক / মধ্য / উচ্চ / মহাবিদ্যালয় / অন্যান্য
স্ত্রী / পুঃ :	_____	________________________	শূণ্য / প্রাথমিক / মধ্য / উচ্চ / মহাবিদ্যালয় / অন্যান্য
স্ত্রী / পুঃ :	_____	________________________	শূণ্য / প্রাথমিক / মধ্য / উচ্চ / মহাবিদ্যালয় / অন্যান্য
স্ত্রী / পুঃ :	_____	________________________	শূণ্য / প্রাথমিক / মধ্য / উচ্চ / মহাবিদ্যালয় / অন্যান্য
স্ত্রী / পুঃ :	_____	________________________	শূণ্য / প্রাথমিক / মধ্য / উচ্চ / মহাবিদ্যালয় / অন্যান্য

বিভাগ ৩: **জ-লর উৎস ও ব্যবহার**

(এ বা আ লিখ-ব, এ=এখনকার, আ=আ-গকার ব্যবহৃত জ-লর উৎস । গৃ= গৃহস্থালির নিজস্ব, সা= সার্বজনিন। প্র-য়জনিয় তথ্যাদি মন্তব্য র বিভা-গ লিখ-ব।)

এখনকার বা আ-গকার ব্যবহৃত (এ / আ)	নদী	পুকুর / হ্রদ	নলকূপ		*বৃষ্টি		*কু-য়া		*নল বাহিত		*ফিল্টার		অন্যান্য (-বা-তা-লর জল -ক-ন?)	মন্তব্য (নলকূ-পর গভীরতা, আ-র্সনিক আ-ছ কিনা? কি ধর-ণর ফিল্টার ব্যবহৃত হয়?)
			গৃ	সা	গৃ	সা	গৃ	সা	গৃ	সা	গৃ	সা		
খাবার / রান্নার					•	•	•	•	•	•	•	•		
স্না-নর/ পরিচ্ছন্নতার														

বাসন মাজবার / কাপড় কাচবার														
-শ-চর														
-পাষ্য-দর														

[= দূষণমুক্ত জলের উৎস (দূঃ জঃ উঃ)]*

৪. ও-পা-রর ছক পূর্ণ কর-ত -য সমস্ত প্রশ্ন করা -য-ত পা-র, তার কিছু নমুনা:
- আপনি জল -কাথা -থ-ক পান? -সই জল কি-সর কা-জ লা-গ: খাবার, রান্নার, না বাসন মাজবার / কাপড় কাচবার?
- আ-গ আপনি বাড়ির জল -কাথা -থ-ক নি-তন?
- আপনি কি ফিল্টার ব্যবহার ক-রন? (-কান ম-ডল?)
- আপনি কি আ-গ -কা-না দিন ফিল্টার ব্যবহার ক-র-ছন? (-কান ম-ডল?)
- নলকূপটা কার? / নলকূপটার মালিক -ক?
- নলকূপটার গভীরতা কত? ____________________________ **(মিটার)**
- নলকূ-পর জ-ল কি আ-র্সনিক আ-ছ? *(-গাল কর)* **হ্যাঁ / জানা -নই / না**

বিভাগ ৪:

রান্নার ও খাবার কা-জ ব্যবহৃত দূষণমুক্ত জ-লর উৎস (দূঃ জঃ উঃ) *(ও-পা-রর ছ-কর • চিহ্নিত -খাপ -দখ)*

যদি দূষণমুক্ত জ-লর উৎস (দূঃ জঃ উঃ) -কানদিন ব্যবহৃত -হয় না থা-ক, তাহ-ল এই -খা-প □ ঠিক চিহ্ন দি-য় বিভাগ ৫ এ চ-ল যাও।

নিম্নলিখিত প্রশ্ন গুলি আপনার গৃহস্থালির এখনকার (এ) বা আগেকার (আ) *(-য -কান একটি -ক -গাল কর)* খাবার জ-লর জন্য ব্যবহৃত ____________________________ *(দূঃ জঃ উঃ টি এখা-ন ব্যবহার কর-ব)* টি -কন্দ্রিক।

৫. কতদিন ধ-র আপনি এটি ব্যবহার কর-তন / ক-রছি-লন? ____________________________ **মাস**

৬. ____________________________ *(দূঃ জঃ উঃ টি এখা-ন ব্যবহার কর-ব)* টি বাবহার করার আ-গ আপনি এটির কথা -কাথা -থ-ক প্রথম শু-নছি-লন? বিষ-দ বল-বন?

৭. কি কার-ণ আপনার বাড়ি -থ-ক এটি ব্যবহা-রর সিদ্ধান্ত -নওয়া হয়? *(সঠিক টি -গাল কর)* **আপনার সাম-র্থর ম-ধ্য / বাড়ির কাছাকাছি / বন্ধু-দর দ্বারা প্রভাবিত হ-য় / -নতা-দর দ্বারা প্রভাবিত হ-য় / আন্যান্য**

৮. কতক্ষণ -ল-গছিল ____________________________ *(পঃ জঃ উঃ টি এখা-ন ব্যবহার কর-ব)* টি লাগা-ত? **(ঘন্টা / দিন / মাস)** *(উপযুক্ত টি -গাল কর)*

৯. এটি -ক লাগি-য়ছি-লন? *(সঠিক টি -গাল কর)* **বাড়ির -লাক/ পড়শিরা / -বসরকারি সংস্থা / সাকার/ বশ্ববিদ্যালয়/ আন্যান্য**

১০. যিনি/যাঁরা লাগি-য়ছি-লন, তিনি/তাঁরা কি এই কা-জর জ-ন্য -বতন নি-য়ছি-লন? *(-গাল কর)* **হ্যাঁ / জানা -নই / না**

১১. যদি -বতন নি-য় ছা-কন, তাহ-ল তা কত? ____________________ **টাকা প্রতি ঘন্টা / দিন / মাস**

১২. ____________________ *(দূঃ জঃ উঃ টি এখা-ন ব্যবহার কর-ব)* টি কি-ন তা লাগা-ত কচ খরচ হ-য়-ছ? **টাকা**

১৩. এই খর-চর কতটা আপনা-দর বাড়ি -থ-ক ব্যায় করা হ-য়-ছ? ____________________________ **টাকা**

১৪. এই জল -প-ত আপনা-দর কি -কান ভাড়া / শুল্ক দি-ত হয়? ____________________ **টাকা প্রতি মা-স**

১৫. আপনা-দর বাড়ির গড় উপার্যন কত? ____________________________ **টাকা প্রতি মা-স**

১৬. ____________________ *(দূঃ জঃ উঃ টি এখা-ন ব্যবহার কর-ব)* টি আপনার বাড়ি -থ-ক কত দূ-র অবস্থিত? **মিটার /** ____________________________ **মিনিট হাঁটা**

১৭. আপনি জল সংগ্রহ ক-রণ কিভা-ব? *(সঠিক টি -গাল কর)* **-হঁ-ট / সাই-ক-ল/ গাড়ি-ত / আপনার বাড়ি-ত জল সরাসরি -পাঁ-ছ যায় / আন্যান্য**

১৮. যদি জল সরাসরি -পাঁ-ছ যায়, তাহ-ল তার খরচ কত? ________________ **টাকা প্রতি মা-স**

১৯. যদি জল -হঁ-ট / সাই-ক-ল / গাড়ি-ত সংগৃহিত হয়, তাহ-ল -সই কাজ টি ক-রন? *(সঠিক টি -গাল কর)* **প্রাপ্তবয়স্ক মহিলা / প্রাপ্তবয়স্ক পুরুষ / নাবালিকা -ম-য় / নাবালক -ছ-ল**

২০. যদি আপনার বাড়ি-ত জল -হঁ-ট / সাই-ক-ল/ গাড়ি-ত সংগৃহিত হয়, তাহ-ল যিনি/যাঁরা এই কাজটি ক-রন, তিনি/তাঁ-দর প-ক্ষ এই কাজটি শরীরিক ভা-ব *(সঠিক টি -গাল কর)* **কষ্টকর / কষ্টকর নয় / সহজ**

২১. যদি ফিল্টার বাবহার করা, চ-ব জল পরিস্কার কর-ত কচ সময় লা-গ? ______________ **মিনিট**

২২. জল সংগ্রহ করার জন্য সবসময় কি লাইন প-ড়? *(-গাল কর)* **হ্যাঁ / জানা -নই / না**

২৩. যদি লাইন প-ড়, তাহ-ল একজন-ক লাইন-ন গ-ড় কতক্ষণ অ-পক্ষা কর-ত হয়? ________________**মিনিট**

২৪. আপনা-দর বাড়ি-ত দি-ন কতবার জল সংগ্রহ কর-ত হয়? ___________***(#)***

২৫. খাওয়ার আ-গ কি জ-ল -কানরকম রাসায়নিক পদার্থ /ওষুধ -মশা-না হয়? *(-গাল কর)* **হ্যাঁ / জানা -নই / না**

২৬. যদি -মশা-না হয়, তাহ-ল কি রাসায়নিক পদার্থ /ওষুধ আর তার পরিমাপ কত/ কতখানি রাসায়নিক পদার্থ /ওষুধ -মশা-না হয়? বিষ-দ বল-বন? __.

২৭. -ক জল টি আপনারা খান, -সটির স্বাদ আপনি -বাঝা-বন কিভা-ব? *(সঠিক টি -গাল কর)* **খুব ভাল/ ভাল/ ঠিকঠাক বা -কান স্বাদ বিহিন / খারাপ / খুব খারাপ**

২৮. খাবার জ-লর রঙটি -ক আপনি -বাঝা-বন কিভা-ব? *(সঠিক টি -গাল কর)* **একদম পরিস্কার / পরিস্কার / ঠিকঠাক / অপরিস্কার / খুব পরিস্কার**

২৯. আপনার বাড়ির -কউকি বি-শষ একটি সম-য়র ব্যবধা-ণ ________________________*(দুঃ জঃ উঃ টি এখা-ন ব্যবহার কর-ব)* টি ঠিক মত কাজ কর-ছ কিনা চা পরিক্ষা ক-রন? *(-গাল কর)* **হ্যাঁ / জানা -নই / না**

৩০. *যদি ক-রন, তাহ-ল :*

-ক ক-রন?

কতদিন অন্তর ক-রন? ____________________________***(#)* প্রতি মা-স**

তিনি/তাঁরা কি এ বিষ-য় -কাথাও শিক্ষা লাভ ক-র-ছন? বিষ-দ বল-বন?

৩১. তিনি/তাঁরা কত ঘন্টা এ বিষ-য় শিক্ষা -প-য়ছি-লন? _________________________**ঘন্টা**

৩২. তাঁ-ক/তাঁ-দর কি এই কা-জর জ-ন্য পারিশ্রমিক -দওয়া হয়? *(-গাল কর)* **হ্যাঁ / জানা -নই / না**

৩৩. -দওয়া হ-ল তা কত? _______________________**টাকা প্রতি মা-স**

কতবার তাঁ-ক/তাঁ-দর এই কা-জর জ-ন্য পারিশ্রমিক -দওয়া হয়? _____________________***(#)* প্রতি মা-স**

৩৪. আপনি কি বিশ্বাস ক-রন -য যিনি/যাঁরা এই কাজটি ক-রন, তিনি/তাঁরা সঠিক ভা-ব পরিচর্যা বা পরীক্ষা ক-রন?*(-গাল কর)* **হ্যাঁ / জানা -নই / না**

৩৫. আপনি কত ঘনঘন পরিচর্যা বা পরীক্ষা করাটা -দ-খন? **একদমই নয় / খুব কম / বি-শষ সময় আন্তর / খুবই ঘনঘন**

৩৬. যিনি/যাঁরা পরিচর্যা/পরীক্ষা করাটা -দ-খন, আপনি তাঁ-ক/তাঁ-দর কত ঘনঘন তা করার কথা ব-লন? **একদমই নয়/ খুব কম/ বি-শষ সময় আন্তর/খুবই ঘনঘন**

৩৭. *যদি না ক-রন, তাহ-ল :*

বাই-রর -কউ কি বি-শষ সময় আন্তর পরিচর্যা/পরীক্ষা ক-রন?

কতদিন অন্তর ক-রন? ____________________________***(#)* প্রতি মা-স**

৩৮. তিনি/তাঁরা কি এ বিষ-য় -কাথাও শিক্ষা লাভ ক-র-ছন? বিষ-দ বল-বন?

৩৯. তিনি/তাঁরা কত ঘন্টা এ বিষ-য় শিক্ষা -প-য়ছি-লন? _________________________**ঘন্টা**

৪০. তাঁ-ক/তাঁ-দর কি এই কা-জর জ-ন্য পারিশ্রমিক -দওয়া হয়? *(-গাল কর)* **হ্যাঁ / জানা -নই / না**

৪১. -দওয়া হ-ল তা কত? _______________________**টাকা প্রতি মা-স**

কতবার তাঁ-ক/তাঁ-দর এই কা-জর জ-ন্য পারিশ্রমিক -দওয়া হয়? _____________________***(#)* প্রতি মা-স**

৪২. আপনি কি বিশ্বাস ক-রন -য যিনি/যাঁরা এই কাজটি ক-রন, তিনি/তাঁরা সঠিক ভা-ব পরিচর্যা বা পরীক্ষা ক-রন?*(-গাল কর)* **হ্যাঁ / জানা -নই / না**

৪৩. আপনি কত ঘনঘন পরিচর্যা বা পরীক্ষা করাটা -দ-খন? **একদমই নয় / খুব কম / বি-শষ সময় আন্তর / খুবই ঘনঘন**

৪৪. যিনি/যাঁরা পরিচর্যা/পরীক্ষা করাটা -দ-খন, আপনি তাঁ-ক/তাঁ-দর কত ঘনঘন তা করার কথা ব-লন? **একদমই নয়/ খুব কম/বি-শষ সময় আন্তর/ খুবই ঘনঘন**

৪৫. যিনি/যাঁরা পরিচর্যা/পরীক্ষা করাটা -দ-খন, আপনি তাঁর/তাঁ-দর কর্তৃপক্ষ-ক কত ঘনঘন তা করার কথা ব-লন? **একদমই নয় / খুব কম / বি-শষ সময় আন্তর / খুবই ঘনঘন**

৪৬. ________________________ *(দুঃ জঃ উঃ টি এখা-ন ব্যবহার কর-ব)* টি -থ-ক বর্জ্য উৎপন্ন হয়?*(-গাল কর)* **হ্যাঁ / জানা -নই / না**

৪৭. যদি বর্জ্য উৎপন্ন হয়, তাহ-ল তা কত খানি? ________________________ **লিটার প্রতি দিন**

৪৮. যদি বর্জ্য উৎপন্ন হয়, তাহ-ল -যই স্থা-ন এই বর্জ্য পরিত্যাগ করা হয়, -সই স্থানটি আপনার বাড়ি -থ-ক কতদূ-র অবস্থিত? **মিটার**

৪৯. যদি বর্জ্য উৎপন্ন হয়, তাহ-ল এই বর্জ্য পরিত্যাগ করার খরচ কত? __________________**টাকা প্রতি মা-স**

৫০. _________________________________*(দুঃ জঃ উঃ টি এখা-ন ব্যবহার কর-ব)* টি কতদিন পর্যন্ত ঠিকঠাক কাজ ক-র? **বছর**

বিভাগ ৫: **ব্যদহারকারী-দর মতামত**

পরবর্তী প্রশ্নগুলো সাধারণভাবে দূষণমুক্ত প্রস্তুতির প্রযুক্তি বিষয়ক। এদের উদ্দেশ্য হল আপনাদের নিজেদের কাছে ও পরিবারে এই প্রযুক্তির গুরুত্ব ও বৈশিষ্ট্যগুলে কচটা প্রয়োজনীয় সে বিষয়ে নির্ভূল অবহিতি। আনুগ্রহ করে নির্ভূল উত্তর দিয়ে সহযোগিচা কর-বন।

নিম্নোক্ত বিষয়গুলা আপনার কাছে কতটা প্র-য়াজনীয়:

		এ-কবা-রই অপ্র-য়া জনীয়	অপ্র- য়াজন ীয়	অপ্র-য়া জনীয়ও নয়, প্র-য়াজন ীয়ও নয়	প্র-য়া জনীয়	খুবই প্র-য়া জনীয়	কোনও উত্তর নেই
৫১	প্রকল্প স্থাপনের আগে আপনার সঙ্গে আলাচনা করা।	-২	-১	০	+১	+২	X
৫২	সিদ্ধান্ত গ্রহণের ক্ষেত্রে সক্রিয় অংশগ্রহণ।	-২	-১	০	+১	+২	X
৫৩	পরিবা-রর -কানও সদ-স্যর, সিদ্ধা-ন্তর বিষ-য় অংশগ্রহণ।	-২	-১	০	+১	+২	X
৫৪	পদ্ধতিটি পরি-বশ-সহায়ক হি-স-ব পরিকল্পিচ কিনা।	-২	-১	০	+১	+২	X
৫৫	প্রকল্পটি / পদ্ধতিটি আকা-র ক্ষুদ্র জায়গায় ক্রিয়াশীল কিনা।	-২	-১	০	+১	+২	X
৫৬	৫১. প্রকল্পটির নির্মা-ণ -য -য ধর-ণর উপাদান ব্যবহৃত হ-য়-ছ।	-২	-১	০	+১	+২	X
৫৭	প্রকল্পটির বাসস্থান থেকে দূরত্ব।	-২	-১	০	+১	+২	X
৫৮	প্রকল্পটির শুদ্ধ জল প্রস্তুত করার -বগ।	-২	-১	০	+১	+২	X
৫৯	প্রকল্প স্থাপন বিষয়টি সমপূর্ণ -বাঝা আ-ছ কিনা।	-২	-১	০	+১	+২	X
৬০	প্রকল্প -থ-ক পাওয়া শুদ্ধ জল আপনার সামর্থ-র ম-ধ্য কিনা।	-২	-১	০	+১	+২	X
৬১	প্রকল্পটি বিদ্যুতচালিত কিনা।	-২	-১	০	+১	+২	X
৬২	প্রকল্পটি নির্ভর-জাগ্য কিনা।	-২	-১	০	+১	+২	X
৬৩	প্রকল্প স্থাপ-নর আ-গ বিভিন্ন প্রক-ল্পর ম-ধ্য -থ-ক একটি -ক পছ-ন্দর সু-যাগ ছিল কিনা।	-২	-১	০	+১	+২	X
৬৪	জলের গুণমান নিয়মিচ পরীক্ষা করা হয় কিনা।	-২	-১	০	+১	+২	X
৬৫	প্রকল্পটির কাজকর্ম ঠিকমত জানা আ-ছ কিনা।	-২	-১	০	+১	+২	X
৬৬	দূষণমুক্ত জল - যা এই প্রক-ল্প প্রস্তুত হয় - তার স্বাদ ভাল কিনা।	-২	-১	০	+১	+২	X
৬৭	প্রাপ্ত জল অস্বচ্ছ কিনা।	-২	-১	০	+১	+২	X
৬৮	প্রক-ল্পর রক্ষণা-বক্ষণ পদ্ধতি ঠিকমত জানা আ-ছ কিনা।	-২	-১	০	+১	+২	X
৬৯	যিনি প্রাপ্ত জল পরীক্ষণ এবং প্রকল্প রক্ষণা-বক্ষ-ণর দায়ি-ত্ব র-য়-ছন, তিনি অ-র্থর বিনিম-য় এ কাজ ক-রন কিনা।	-২	-১	০	+১	+২	X
৭০	যিনি প্রাপ্ত জল পরীক্ষণ এবং প্রকল্প রক্ষণা-বক্ষ-ণর দায়ি-ত্ব র-য়-ছন, তিনি প্রশিক্ষণ প্রাপ্ত কিনা।	-২	-১	০	+১	+২	X
৭১	দায়িত্বপ্রাপ্ত কর্মীকে প্রয়োজনীয় ক্ষেত্রে দায়ী করা যায় কিনা।	-২	-১	০	+১	+২	X
৭২	দূষণমুক্ত জল পেতে হবে - এটি নি-জ-দর সিদ্ধান্ত ছিল না বাই-রর -কানও পরাম-র্শর মাধ্য-ম গৃহীত হ-য়ছিল?	-২	-১	০	+১	+২	X
৭৩	প্রকল্প -থ-ক পাওয়া শুদ্ধ জল বিনামূ-ল্য	-২	-১	০	+১		X

	পাওয়া যায় কিনা।						
৭৪	পরিবারের সকলে আর্সেনিক যুক্ত জল পানের শারীরিক প্রতিক্রিয়া বিশয়ে জানেন কিনা।	-২	-১	০	+১	+২	X
৭৫	প্রকল্পের রক্ষণাবেক্ষণে নিযুক্ত কর্মীর অধীক্ষক হি-স-ব -কউ আ-ছন?	-২	-১	০	+১	+২	X
৭৬	প্রক-ল্প প্রস্তুত জ-লর -কানও উগ্র স্বাদ আছ কিনা?	-২	-১	০	+১	+২	X
৭৭	প্রকল্প বাড়ি -থ-ক কাছাকাছি কিনা।	-২	-১	০	+১	+২	X
৭৮	প্রক-ল্প -ছাটখাট সংস্কার কর-ত হয় কিনা।	-২	-১	০	+১	+২	X
৭৯	প্রকল্প -থ-ক প্রাপ্তজ-ল কতটা আ-র্সনিক থাক-ছ, তা জানা আ-ছ কিনা।	-২	-১	০	+১	+২	X
৮০	প্রকল্প -থ-ক কঠিন বা চরল বর্জ্য উৎপন্ন হয় কিনা।	-২	-১	০	+১	+২	X
৮১	প্রকল্প -থ-ক যদি বর্জ্য উৎপন্ন হয়, তাহ-ল চা বাসস্থা-নর কাছাকাছি -ফলা হয় কিনা।	-২	-১	০	+১	+২	X
৮২	প্রকল্প -থ-ক যদি বর্জ্য উৎপন্ন হয়, তাহ-ল চা প্রক-ল্পর কাছাকাছি -ফলা হয় কিনা।	-২	-১	০	+১	+২	X
৮৩	প্রক-ল্প পুনর্ব্যবহ্যর বা পুনরুৎপাদ-নর ব্যবস্থা আ-ছ কিনা।	-২	-১	০	+১	+২	X

		এ-কবা-রই না	না	নাও নয়, হ্যাঁও নয়	হ্যাঁ	-জা-র সঙ্গে হ্যাঁ	কোনও উত্তর নেই
৮৪	আমি মনে করি, দূষণমুক্ত জল প্রকল্পটি আকা-র যত -ছাট হয় ততই ভাল।	-২	-১	০	+১	+২	X
৮৫	আমি মনে করি, দূষণমুক্ত জল প্রকল্পটি -যন পূণরব্যবহৃত দ্রব্যাদি দি-য় তৈরী হয়।	-২	-১	০	+১	+২	X
৯১	আমি মনে করি, দূষণমুক্ত জল প্রকল্পটি আমার বাড়ির যত কা-ছ হয় ততই ভাল।	-২	-১	০	+১	+২	X
৮৬	যাদের সামর্থ্য আছে, তাদের দূষণমুক্ত জলের কর -দওয়া উচিত।	-২	-১	০	+১	+২	X
৮৮	আমার মতে সার্বজনিন দূষণমুক্ত জল প্রকল্প ব্যবহার করার -থ-ক নি-জর বাড়ি-ত দূষণমুক্ত জল প্রকল্প থাকাটা কাম্য।	-২	-১	০	+১	+২	X
৮৯	সার্বজনিন দূষণমুক্ত জল প্রকল্প থাকাটাই আমার যুক্তিযুক্ত মনে হয়।	-২	-১	০	+১	+২	X
৯০	আমি নিজস্ব জল পরি-ষাধক (ওয়াটার ফিল্টার) -দখাশু-না কর-ত পছন্দ করি না।	-২	-১	০	+১	+২	X
৯১	জল দূষণমুক্ত করবার জন্য যে রাসায়ণিক -যৗগ ব্যবহার কারি হয়, তা কাম্য নয়।	-২	-১	০	+১	+২	X
৯২	অন্যের কাছ থেকে দূষণমুক্ত জল প্রকল্পের নাম না -জ-ন, আমি পছন্দ করি নি-জ -জ-নশু-ন তা পছন্দ কর-ত।	-২	-১	০	+১	+২	X
৯৩	জল সক-লর জন্য বিনামূল্য হওয়া উচিত।	-২	-১	০	+১	+২	X
৯৪	জল দূষণমুক্ত হলে, আমি অল্প স্বাদ সহ জল পা-ন রাজি।	-২	-১	০	+১	+২	X
৯৫	বাড়ি পর্যন্ত জল -পৗ-ছ যাওয়া সব -থ-ক যুক্তিযুক্ত।	-২	-১	০	+১	+২	X
৯৬	আমার মতে যে দূষণমুক্ত জল প্রকল্পটি	-২	-১	০	+১	+২	X

	বিদ্যুৎ চালিত, তা -য প্রকল্পটি বিদ্যুৎ চালিত নয়, তার -থ-ক কম নির্ভর-যাগ্য।						
৯৭	প্রকল্প -থ-ক উৎপন্ন কঠিন বা তরল ব-র্জ্য আ-র্সনিক থাক-ল আমি তা নি-য় ভাবিত নই।	-২	-১	০	+১	+২	X
৯৮	প্রকল্প -থ-ক উৎপন্ন কঠিন বা তরল ব-র্জ্য আ-র্সনিক থাক-ল তা -কাথায় -ফলা হ-চ্ছ, তা নি-য় আমি ভাবিত নই।	-২	-১	০	+১	+২	X
৯৯	দূষণমুক্ত জলের স্বাদ থাকা অনুচিত।	-২	-১	০	+১	+২	X
১০০	আমি কেবলমাত্র স্বচ্ছ জলই পান করি।	-২	-১	০	+১	+২	X
১০১	দূষণমুক্ত জল সংগ্রহ করবার আমি অল্প দূরত্ব অতিক্রম করতে রাজি।	-২	-১	০	+১	+২	X
১০২	বহিরাগত -কান দ-লর ব-ল -দওয়া -কানও দূষণমুক্ত জল প্রকল্পের নাম আমি বিশ্বাস করব।	-২	-১	০	+১	+২	X

১০৩. দূষণমুক্ত জল সংগ্রহ করবার জন্য কতটা দূরত্ব অতিক্রম করতে পারেন? মিটার

১০৪. দূষণমুক্ত জল সংগ্রহ করবার জন্য কতটা দূরত্ব অতিক্রম করা যুক্তিযুক্ত মনে হয়। মিটার

১০৫. প্রতি বালতি জল শিধ-নর জন্য কতক্ষণ অ-পক্ষা কর-ত পা-রন? ________________________মিটার

১০৬. প্রতি বালতি জল শিধনের জন্য কতক্ষণ অপেক্ষা করা যুক্তিযুক্ত মনে হয়। মিটার সপ্তা-হ কতবার প্রকল্প রক্ষণা-বক্ষ-ণ আপনি অংশ নি-ত ইচ্ছুক?

১০৭. জল দূষণপ্রকল্প ক্রয়ের হন্য প্র-য়াযনীয় ব্য-য়র কতটা আপনার পরিবার বহন কর-ত ইচ্ছুক?

১০৮. এরকম প্রকল্প স্থাপনের ব্যয় কত হলে আপনার পক্ষে যুক্তিযুক্ত মনে হয়।

১০৯. বিশুদ্ধ জ-লর জন্য আপনার পরিবার মা-স কত টাকা ব্যয় কর-ত ইচ্ছুক?

১১০. বিশুদ্ধ জলের জন্য আপনার পরিবারে মাসে কত টাকা ব্যয় আপনার যুক্তিযুক্ত মনে হয়?

আপনার সহ-যাগিতার জন্য ধন্যবাদ। আমাদের সঙ্গে কথা বলবার জন্য আপনি যে সময় দিয়েছেন আমরা বাধিত। নমস্কার।

Appendix II: Technical Data Check List Per Village

Community Information

Date

Name of village & district

GPS coordinates

Elevation

Number of houses

Estimated population

Number of wells

General location of wells

Sources of water available

Physical distances to sources

Ownership of wells

Religion

Political Involvement

Well Information

Well depth(s)

GW height

Type of pump (hand or electric)

Flow rate(s)

[As] of raw water

Number of people using each well

(Average) Distance to well

Presence of wellhead filter unit

CWT Information

Make/Model

Installation date

Removal mechanism

[As] of treated water

Flow rate

Volume of treated water produced per day

Time spent treating water

Dimensions (size)

Mass

Materials used in construction

Replaceable parts

Instructions present

Maintenance guidelines present

Volume of sludge produced per day

[As] of sludge

Number of waste dumping sites

General location(s) of waste dumping sites

Appendix III: Detailed Letter of Explanation

Naturally-occurring arsenic (a well-known poison), is present in the well-water of over 50 million rural residents in the Bengal Basin (India and Bangladesh). It is important for the people affected by this contamination that the most appropriate and sustainable clean-water technologies are implemented to ensure safe drinking water. At the present time, this is not happening, as the vast majority of arsenic-removal or avoidance technologies implemented fail within the first year. These technologies need to be correctly assessed.

The purpose of this project is to create a transparent and standardised evaluation methodology which will enable decision-makers to select and promote the best, long-term and appropriate solutions for the affected communities. This will be done by using the Process Analysis Method (PAM) to create triple-bottom line, sustainability assessments. This method is rooted in engineering systems theory which first requires defining both sustainability and the system's boundaries. In the case of this project, the boundary is set at a community level. The framework for the metric is created by identifying economic, sociocultural and environmental impact generators and receivers, which lead to the characterisation of meaningful indicator sets. These will highlight the degree to which a technology is environmentally friendly, socio-culturally appropriate and economically viable which will be used in the creation of a sustainability index allowing the technologies to be compared to each other numerically.

Most of the technical data is available online allowing me to fill in the values for the environmental and economic indicators for each technology fairly easily. However since this project is user-focused, the technology users must be consulted to quantify the reality and priority of various socio-cultural aspect of the technology. I need to understand the process of engagement during the installation process, and to know the distance the user is walking to collect water, the time spent filtering, number of times a day water is collected, the degree to which the colour and taste are acceptable, whether they are physically and technically able to conduct regular maintenance, if there is an incentive for filter, or accountability for regular maintenance, and where waste is disposed of. I also need to learn the degree of importance and priority of these factors to the user. It is not necessary for me to ask the individual’s name or record their contact details (address and phone number) for my research. However I do need to record the village name they live in, their gender, age, number of people living in the home, levels of education, and average monthly income. Please note that this personal data will be manipulated statistically and never published in its raw form.

Gathering this information requires me to conduct field work so I will be travelling to various villages around the Kolkata region in West Bengal, India. I will be accompanied by my local translator and we will conduct door-to-door surveys in these villages. The total sample number is chosen based upon the number of households that exist within each community, and each household will be chosen randomly (perhaps every third or fourth house in a row). We will approach the randomly selected home and ask to speak with an adult. We will then introduce ourselves and continue using the script (see top of survey) to obtain informed consent verbally. This will be done in Hindi, Bengali or English. If the individual wishes to participate, we will ask the questions as listed on the survey verbally to the participant and fill in the survey ourselves with the participant’s answers. If the individual does not wish to participate then a business card will still be left, they will be thanked and we will move on to the next house. We will also be recording the start and finish time for each survey to ensure that on average we are giving them an accurate time estimate. A technical data check list will be completed for each village surveyed and given a code which will be recorded at the top of each survey for organizational purposes. The surveys and technical data will be scanned and saved as pdf files in a secure folder on my computer. The hard copies will be destroyed.

Verbal informed consent will be obtained for any photos taken inside homes (or any private location).

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Department of Engineering Science

Appendix III: Participant Information Sheet

Name of Research Project: Accounting for Sustainability of Clean-Water Technologies in Bengal

Principal Investigator: Tamara Etmannski, Doctoral Student; c/o St. Edmund Hall, Queens Lane, Oxford, United Kingdom, OX1 4AR; +44 (0)775 806 7992; tamara.etmannski@eng.ox.ac.uk

Purpose of the Study: To gather information related to water filters or clean water strategies from community members/users, with the purpose of using this information to create a method of technology evaluation that accurately represents the values and priorities of the community/user. This user-focused evaluation will enable decision-makers to select and promote the best, long-term and appropriate solutions for the affected communities.

As a Participant: You are being invited to take part in this study because the clean-water technology used in your community is being evaluated and your feedback on issues like user-ability, reliability and economic viability are valuable to the success for this research.

Your participation will involve answering one household survey that will take between 15-20 minutes to complete. Questions will be asked orally in your native tongue (English, Bengali or Hindi) at your doorstep, at the time of first contact by the door-to-door local surveyors.

Please ask questions about the study before you decide whether to participate. If you agree to participate, you may withdraw from the study without penalty at any time by advising the researchers of this decision.

This project has been reviewed by, and received ethics clearance through the University of Oxford Central University Research Ethics Committee.

The University of Oxford is committed to the dissemination of its research for the benefit of society and the economy and, in support of this commitment, has established an online archive of research materials. This archive includes digital copies of student theses successfully submitted as part of a University of Oxford postgraduate degree programme. Holding the archive online gives easy access for researchers to the full text of freely available theses, thereby increasing the likely impact and use of that research. If you agree to participate in this project, the research will be written up as a thesis. On successful submission of the thesis, it will deposited both in print and online in the University archives, to facilitate its use in future research. The thesis will be published with open access, meaning available to every internet user. This research also may be published in peer-reviewed academic journals, and may be used in research dissemination strategies including all modes of multi and social media, accessible internationally. All personal data collected will be securely stored by the researcher in hard copy and electronic copy for potential future use or reference.

No benefit (direct or indirect) may accrue to the participants in the study and there are no risks involved in participating in this study.

If you have a complaint or concern about any aspect of this project, please speak to the researcher concerned (Tamara Etmannski, +44 (0)775 806 7992) who will do her best to answer your query. If you remain unhappy and wish to make a formal complaint, please contact the Research Ethics Committee at the University of Oxford (ethics@socsci.ox.ac.uk; +44 (0)1865 614871; Social Sciences & Humanities Inter-Divisional Research Ethics Committee, Oxford University, Hayes House, 75 George Street, Oxford, OX1 2BQ, UK).

Thank you for your time.

University of Oxford

Department of Engineering Science

Appendix III: Consent of a Research Participant

Name of Research Project: Accounting for Sustainability of Clean-Water Technologies in Bengal

Principal Investigator: Tamara Etmannski, Doctoral Student

Purpose of the Study: To gather information related to water filters or clean water strategies from community members/users, with the purpose of using this information to create a method of technology evaluation that accurately represents the values and priorities of the community/user.

Participant Declaration:

I confirm that I have read the participant information sheet and understand its contents.

I confirm that I had the opportunity to ask questions about the study and have received satisfactory answers to questions, and any additional details requested.

I acknowledge that any photographs taken of me will not be owned by me.

I understand that any photographs taken of me or any information I provide during my participation in this research project, may be distributed in any medium in any part of the world.

[I understand that my photographs may be edited and there is no guarantee that my photographs will appear in the final write-up documents. I agree that my contribution may be used to publicize the research.]

I understand that I may withdraw my consent at any time during my participation in the research project and that I do not have to give a reason for my decision. I acknowledge that such withdrawal of my consent will not prejudice my participation in this research project.

I understand that this project has been reviewed by, and received ethics clearance through, the University of Oxford Central University Research Ethics Committee.

I understand how this research will be written up as a student's thesis, posted online in the University of Oxford Archive, may be published in peer-reviewed academic journals, and may be used in research dissemination strategies including all modes of multi and social media.

I understand how my personal data will be stored by the researcher.

I agree to participate in this study.

I understand how to make a complaint or raise a concern about any aspect of this project.

Signed…………………….……..…..……(Participant)

Print Name……….……………….….…(Participant)

Date…………………………………..……(Participant)

Witnessed by…….…………………………(Researcher)

Print name………..….……….………………(Researcher)

Date…………………………………….…..(Researcher)

SOCIAL SCIENCES & HUMANITIES
INTER-DIVISIONAL RESEARCH ETHICS COMMITTEE

Hayes House, 75 George Street, Oxford. OX1 2BQ
Tel: +44(0)1865 614871 Fax: +44(0)1865 614855
ethics@socsci.ox.ac.uk www.socsci.ox.ac.uk

Co-ordinator of the IDREC
Social Sciences Divisional Office

UNIVERSITY OF OXFORD

Monday, 9 July 2012

Tamara Etmannski
Department of Engineering Science

Dear Tamara,

Research Ethics Approval

Ref No.: SSD/CUREC1/12-024

Accounting for Sustainability in Bengal: Examining Arsenic-Removal Technology using Process Analysis Method

The above application has been considered on behalf of the Social Sciences and Humanities Inter-divisional Research Ethics Committee (IDREC) in accordance with the procedures laid down by the University for ethical approval of all research involving human participants.

I am pleased to inform you that, on the basis of the information provided to the IDREC, the proposed research has been judged as meeting appropriate ethical standards, and accordingly approval has been granted.

Should there be any subsequent changes to the project, which raise ethical issues not covered in the original application, you should submit details to the IDREC for consideration.

Yours sincerely,

K. M. Dally

Kathryn Dally

cc: Prof Richard Darton, Department of Engineering Science
Prof Guy Houlsby, Department of Engineering Science

KD/EB

University of Oxford

Department of Engineering Science

Appendix III: Itinerary for Training Session

11:15-11:25	Meet and fill out forms -Emergency Contact Information -Contract
11:30	Meeting begins
11:30-11:40	Introductions
11:40-12:00	Background on Project
12:00-12:10	Safety
12:10-12:20	Ethics
12:20-1:00	Specifics on Household Survey -English / Bengla -Practice, Role Play -Work through Training Sheet
1:00-1:20	Job Specifics -Pay (Amount, Pay day, Food Stipend) -Job Expectations (Hours, Locations, Attitude, Flexibility)
1:20-1:30	Questions / Concerns
1:30-1:45	Determine Morning Meeting Spot
1:45-2:00	Discuss / Modify Schedule

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Department of Engineering Science

Appendix III: Training Notes

Part 1: Background

Naturally-occurring arsenic (a well-known poison), is present in the well-water of over 50 million rural residents in the Bengal basin (India and Bangladesh). It is important for the people affected by this contamination that the most appropriate and sustainable clean-water technologies (CWT) are implemented to ensure safe drinking water. At the present time, this is not happening, as the vast majority of arsenic-removal or avoidance technologies implemented fail within the first year. These technologies need to be correctly assessed.

The purpose of this project is to create a transparent and standardised evaluation methodology which will enable decision-makers to select and promote the best, long-term and appropriate solutions for the affected communities. Since this project is user-focused, the technology users must be consulted to quantify the reality of various socio-cultural aspects of the technology. For example, I need to understand the process of engagement during the installation process, and to know the distance the user is walking to collect water, the time spent filtering, number of times a day water is collected, the degree to which the colour and taste are acceptable, whether they are physically and technically able to conduct regular maintenance, if there is an incentive for filter, or accountability for regular maintenance, and where waste is disposed of. I also need to learn the degree of importance and priority of these factors to the user. It is not necessary for me to ask the individual's name or record their contact details (address and phone number) for my research. However I do need to record the village name they live in, their gender, age, number of people living in the home, levels of education, and average monthly income. Please note that this personal data will be manipulated statistically and never published in its raw form.

Gathering this information requires conducting door-to-door surveys in villages that use different CWTs. The total sample number is chosen based upon the number of households that exist within each community, and each household will be chosen randomly (perhaps every third or fourth house in a row). We will approach the randomly selected home and ask to speak with an adult. We will then introduce ourselves and continue using the script (see top of survey) to obtain informed consent verbally. This will be done in Hindi, Bengali or English. If the individual wishes to participate, we will ask the questions as listed on the survey verbally to the participant and fill in the survey ourselves with the participant’s answers. One surveyor asks questions and one writes down all the answers. If the individual does not wish to participate then a business card will still be left, they will be thanked and we will move on to the next house. We will also be recording the start and finish time for each survey to ensure that on average we are giving them an accurate time estimate. A technical data check list will be completed for each village surveyed and given a code which will be recorded at the top of each survey for organizational purposes. I will be conducting arsenic testing of the raw water, the tested water and the waste produced in each location.

Part 2: Survey

Sampling (selecting houses to survey):

> Depending on the population of a village or number of houses in a community we will be trying to survey 30 houses per 100 (1 in every 3). So you walk down a street and count 3 houses in a row. You approach the third to be surveyed. You

do not survey a house upon request unless their house was the 3rd house picked randomly.

Section 1

Informed consent means you explain to people who you are and what your intentions are and after to ask their permission to participate. If they say no, thank them and move on. Instead of going to the next house, approach the house one behind (the second house).

Section 2

The point of section 2 is to identify the household demographic and also to build a rapport by asking easy questions very early on in the survey.

Section 3

The point here is to identify current and past use of water. Here is a detailed explanation of all the options. You must know these and understand this table in order to understand how to target the survey correctly.

Water Source	Water Type	To make Drinkable:
Rain water	-Rain/Dew	None
	-Rainwater harvesting	Filter and/or Add chemicals
Surface water	-Ponds	Filter
	-Rivers	Filter
Ground water	-Dug wells (young)	Add chemicals
	-Shallow tube wells (old)	Arsenic filter
	-Deep tube wells (very old)	None
Piped	-Treated by corp or gov't	-Piped to village or home

This project is primarily interested in the use of Rainwater, Groundwater and Piped water for drink/cooking purposes. Many people do not use surface water for drinking because of bad bacteria.

It is also important to distinguish whether the tube well is shallow or deep. The only way to know this is to ask the household for the actual depth. Do not ask the household whether it is shallow or deep because they will not understand that I am using a scientific definition. In their opinion, it may be shallow or deep but I don't want their opinion. I want actual depth (or estimated) in meters or feet. It would also be useful to know who owns the tube well (if one is used) or whether the household themselves drilled it, verses some other community member, government or outside organisation. Make sure you distinguish between household level technologies and community-shared technologies, and also, past use versus current use.

Section 4

Using section 3, you need to identify one clean water source (CWS) to focus on and let the household know that for this next section you are only focusing on this technology. It can be a CWS that they currently use, or have used in the past. For example, if they used to use a filter but don't anymore, it is very interesting to understand why they stopped.

Section 5

This section is not about a specific technology, which is why you are to ask these questions even if the household doesn't use any CWT. These questions are asked to help identify the community's values in respect to CWT generally. So please make sure you tell them before starting this section that these questions are more general in nature and to respond based upon their personal opinion.

The last section is a continuation of the first part in section 5, in that we are trying to identify the user's values, however in this last section we are looking for exact numbers that express the worst case scenario that is 'acceptable' (maximum values) and also parameters that would exist in an ideal world (ideal values).

Closing:

Make sure you thank them for their time and cooperation. Ask them if they have any questions before leaving and spend time answering their concerns.

Appendix III: Surveyor Offer Letter

DEPARTMENT OF ENGINEERING SCIENCE
Office 13, 14 Parks Road, Oxford, United Kingdom

Tamara R Etmannski
Doctoral Student in Sustainable Water Engineering
Sub Dean at St Edmund Hall

UNIVERSITY OF OXFORD

August 10, 2012

Dear Surveyor,
Re: Surveyor Position

This letter describes the duties, expectations and remuneration for the on-call surveyor positions.

Four surveyors will be expected to accompany the Oxford Researcher to locations around West Bengal, including day-trips and possible over-night trips. During these trips, teams of two surveyors will travel door-to-door together conducting household surveys. Each survey-team will be expected to fill in between 10-12 surveys per day. The surveyors will be expected to follow all ethical protocols and safety procedures while in the field. The surveyors are also expected to work well with a team, to be flexible, professional, and honest. The surveyors are required to travel to and from an agreed meeting spot by themselves (at their own cost) in the morning before the trip and in the evening after the trip is over. The meeting time in the morning will likely be around 6am, and no tardiness is acceptable. Returning times will vary depending on the day.

Each surveyor may work 0-4 days/week, for the duration of 8-10 weeks beginning the week of July 15, 2012. The salary will be 500 INR per person per day. Surveyors may be expected to work on weekends (Saturday and Sunday). Costs for transportation will be paid for all day-trips (from the central meeting spot). An additional 50 INR per day will be paid to each surveyor so they can pack and bring food and water for themselves for the entire day, each day. Payment of the daily wage and daily food stipend will be made in cash weekly, on the last day of field work for that week. If over-night trips are planned, the costs for transportation, food and accommodation will be paid for the duration of the trip.

If the researcher feels that the above stated obligations are not being met by a surveyor at any time during the 10 week period, the researcher can terminate the term immediately and without notice.

This letter serves as a contract between the researcher and the surveyor that the above statements have been agreed upon by both parties.

____
Signature of Surveyor

____
Signature of Tamara R Etmannski
Oxford Researcher

____
Printed Name of Surveyor

____
Date

____
Date

University of Oxford

Department of Engineering Science

Appendix III: Emergency Contact Information

Name________________________ Mobile Number______________________

Address (with directions)

____

____

Existing allergies or medical conditions (or religious practices that need to be accommodated for during the field day)

____

____

Are you currently taking any medication? Yes / No (circle) If yes,
List:_________________________

Next of Kin____________________ Relationship_______________________

Phone________________________ Alt. Phone_________________________

Address____

____

Please explain what you would or wouldn't like the survey team to do if you were to get injured while working in the field (for example, administer any drugs and/or first aid, drive you to clinic, call an ambulance, call family, etc):

____

____

I acknowledge that while working in this project, I am solely responsible for my own safety. Therefore, by signing this form I formally acknowledged that neither the team leader (Oxford Researcher) nor The University of Oxford or my fellow surveyors are liable for any reason that may result from any situation that may occur during this project.

_____________________________ _____________________________
Print Name (Surveyor) Print Name (Witness-Oxford Researcher)

_____________________________ _____________________________
Sign Name Sign Name

_____________________________ _____________________________
Date Date

Risk Assessment: **Conducting household surveys (door-to-door)**		Page 1 of 2
Location: **Villages surrounding Kolkata, India**		Review Date :
Assessment undertaken by: **Tamara Etmannski**	Signed	Date :
Assessment supervisor: **Richard Darton**	Signed	Date :

Hazard	Persons at Risk	Risk Controls In Place	Further Action Necessary To Control Risk
1. Sun-stroke (heat stroke)	Researcher(s)	-Wear sun cream; Keep hydrated; Wear a hat; limit time spent in direct sunlight	-Start day being well-rested
2. Unhygienic food / water causing digestive problems (parasites, bacterial diarrhoea)	“	-Bring packed lunches; Buy and drink only bottled water; Don’t accept food or drink from anyone	-Wash hands regularly
3. Malaria or Dengue Fever from mosquitos	“	-Take malaria pills (Chloroquine & Proguanil)	-Use bug-repellent and mosquito nets
4. Falling due to rough terrain	“	-Carry first aid kit; Carry a mobile phone and GPS; First aid course taken; Medical insurance bought; Ring ambulance or air evacuation if serious (see attached Info Sheet)	-Wear supportive and appropriate footwear and clothing; Walk carefully
5. Drowning or injury due to flood waters	“	-Carry first aid kit; Carry a mobile phone and GPS; First aid (CPR) course taken; Medical insurance bought; Ring ambulance or air evacuation if serious (see attached Info Sheet)	-Awareness of local surroundings and avoiding flooded regions; Researcher knows how to swim

6. Robbery or being pick-pocketed	“	-Keep valuables in secure pockets or bags; Never leave bags unattended; Wear a secret money pocket	-Never carry large sums of cash; Don’t wear flashy jewellery or clothes; Never work after dark; Never enter into obvious unsafe areas
7. Harassment	Researcher(s)	-Work in pairs; Carry a mobile phone and GPS; Be conscious of local norms of attire and behaviour; Travel with local translator	-Never work after dark; Never enter into obvious unsafe areas
8. Vehicle accident during hired-car & driver transport	“	-Chose reputable car company; Ensure driver is well-rested prior to trip; Ensure driver abides by road rules	-Note: Cars are not normally equipped with seatbelts in Kolkata, India
9. Loss of contact	“	-See attached Info Sheet for full India, UK and Canada contact details	-Researcher is in contact with the host family daily and the host family is knows the details of the researcher’s daily itinerary; Check in with supervisor once per week through email; Skype with family once per week
10. Snake bite (Indian Cobra, Common Krait, Russell’s Viper, Saw-scaled Viper)	“	-Avoid marshy areas, rice paddys, mounds of rubble or trash; Avoid walking at night; If bitten proceed to nearest hospital immediately (1 to 5 hours to live without anti-venom)	-Knowledge on recognising local snakes and their typical behaviour