Technological innovations for societal change

Arsenic mitigation technologies for safe drinking water in rural Bangladesh

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Debasish Kumar Kundu

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To my parents,

Rekha Kundu and Kalidas Kundu

To my teacher,

Late National Professor Dr Rangalal Sen

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List of abbreviations

AAN	Asia Arsenic Network
ATN	Actor Network Theory
ADAMS	Association for Development Activity of Manifold Social-work
BCSIR	Bangladesh Council for Scientific and Industrial Research
BGS	British Geological Survey
BRAC	Bangladesh Rural Advancement Committee
BUET	Bangladesh University of Engineering and Technology
CIDA	Canadian International Development Agency
CIM	Composite Iron Matrix
DANIDA	Danish International Development Agency
DCH	Dhaka Community Hospital
DESCO	Dhaka Electric Supply Company
DLB	Die Licht Brucke
DPHE	Department of Public Health Engineering
DU	University of Dhaka
ETVAM	Environmental Technology Verification for Arsenic Mitigation
GGC	Good Gift Catalogue
GO	Government Organization
GoB	Government of Bangladesh
HDRC	Human Development Resource Centre
IDE	International Development Enterprises
IPAM	Implementation Plan for Arsenic Mitigation
JICA	Japan International Cooperation Agency
LGIs	local government institutions
MLP	Multi-level Perspective
MSUK	Manob Sakti Unnayan Kendro
NAISU	Arsenic Information & Support Unit
NAMP	National Arsenic Mitigation Policy
NGO	Non Government Organization
NWO	Organisation for Scientific Research
OECD	Organization for Economic Cooperation and Development

PVC	Poly Vinyl Chloride
SAR	Sub-surface arsenic removal
SCOT	Social Construction of Technology
SEDA	Socio Economic Development Agency
SNM	Strategic Niche Management
SSF	Shishu Sasthyo Foundation
TIS	Technological Innovation System
TM	Transition Management
UNICEF	United Nations Children’s Fund
UP	Union Parishad
VERC	Village Education Resource Center
WATSAN	Water, Sanitation and Hygiene
WB	World Bank
WHO	World Health Organization
WOTRO	Foundation for Scientific Research of the Tropics and Developing Countries
WSP	Water Safety Plan

Chapter 1

Introduction

1.1 Statement of the problem

1.1.1. Safe drinking water and arsenic contamination

Safe drinking water is a basic requirement for human existence yet its provision remains a challenge, particularly in developing countries (WHO, 2013, Pruss-Ustun et al., 2014). Although there has been considerable progress in providing pathogen-safe drinking water, groundwater arsenic contamination is now recognised as one of the world's greatest environmental disasters, threatening the lives of about 150 million people (Ravenscroft et al., 2009). Arsenic, a well-known pollutant considered as one of the most hazardous chemicals, prevails in inorganic and organic forms in the terrestrial environment. The inorganic form of arsenic, such as trivalent As III and pentavalent As V, are more widespread and poisonous than the organic forms in general (Shankar et al., 2014). Groundwater arsenic contamination has thus emerged as an alarming problem on a global scale and has already been reported in seventy countries (See Figure 1.1). Among them, Bangladesh has been reported as the worst affected country in terms of severity and extent of contamination, and the number of arsenic victims, by what it is said to be the largest mass poisoning in the history of mankind (WHO, 2000; DPHE, 2001; Brinkel et al., 2009).

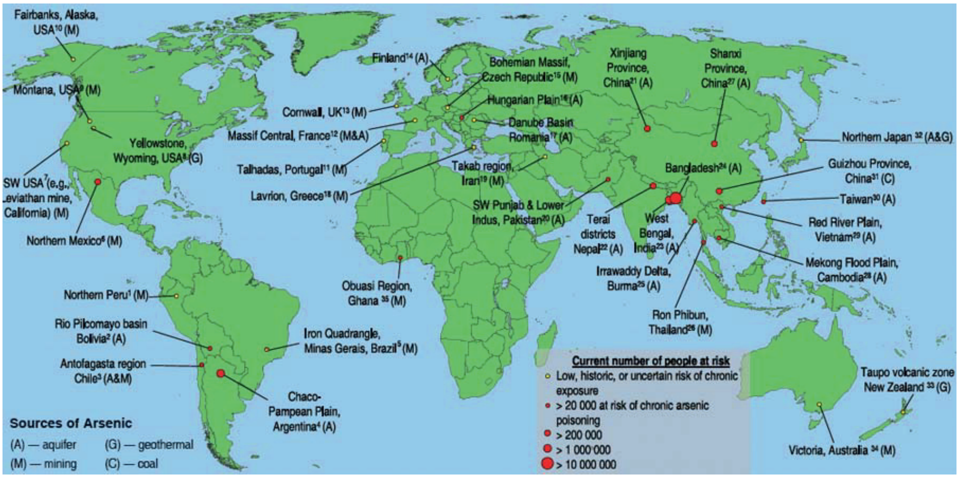

Figure 1.1: Worldwide distribution of arsenic contaminated regions, showing the source of arsenic and number of people at risk of chronic exposure (Garelick & Jones, 2008).[1]

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[1] Without conducting geochemical survey, it is difficult to quantify the number of people who are at risk of arsenic contamination. This estimation depends on four criteria: 1) prevalence of current recorded cases of arsenicosis; 2) likelihood of ingested concentrations exceeding 50µg/L; 3) number of people living in exposed areas; and 4) likely ability of region to mitigate/remediate against contamination (Hemda & Huw, 2008, cited in Thakur et al., 2011: 4).

Before the 1970s, the rural people of Bangladesh relied mainly on surface water, which exposed them to the threat of pathogen contamination. Due to a coordinated effort by the public and private sectors, Bangladesh achieved a 'safe drinking' water coverage of 97 percent of the rural population at the end of the 1990s, a major achievement. This was done mostly through installation of 10million shallow hand pump tube wells during the 1970s-1990s (Khan, 2012; Hossain et al., 2015). The shallow hand pump tube well has since become the taken-for-granted safe water infrastructure in rural Bangladesh, except for certain saline-prone and hill tract areas. This favourable situation persisted until naturally occurring arsenic was detected in ground water in Bangladesh in 1993 (Alam et al., 2002), leading to the problem of arsenic contamination of the main source of rural safe drinking water supply. Consequently, rural safe drinking water coverage dropped to 72.3 percent. This also had the consequence that Bangladesh's prospects of achieving the Millennium Development Goal 7, Target 3aimed at halving by 2015 "the proportion of population without sustainable access to safe drinking water and basic sanitation" was adversely affected (Kabir & Howard, 2007; DPHE & JICA, 2009; see also Rammelt et al., 2014).[2] Provision of safe drinking water remains a major challenge in the post-2015 development agenda for Bangladesh.[3]

According to the World Health Organization (WHO), the maximum permissible limit of arsenic in drinking water is 10 µg/L, whereas the limit is 50 µg/L in Bangladesh, like in many other developing countries (Hossain et al., 2006). The first systematic survey of the extent of the arsenic contamination problem conducted in 1998-99 showed that 27 percent of all rural shallow hand pump tube wells are contaminated by arsenic (BGS & DPHE, 2001). Depending on what threshold level of arsenic is considered, it is estimated that this meant that approximately 22-35 (or 57-77) million people were exposed to arsenic through drinking arsenic-contaminated water (Milton et al., 2012; Hossain et al., 2015). Arsenic contamination is found to be prevalent in 322 out of 460 Upazilas (administrative sub-districts) in 61 out of the 64 districts in Bangladesh, although the magnitude of the problem is not the same everywhere (See Figure 1.2).

1.1.2. Health and social consequences of arsenic contamination

The adverse effect of arsenic on public health is commonly known as arsenicosis, whichrefers to a wide variety of diseases ranging from skin lesions to cardiovascular diseases and even cancer (Paul, 2004; Khan & Yang, 2012). A recent study estimates that the number of arsenic-attributed deaths in Bangladesh is about 43,000 per year, which represents about 5.6 percent of all deaths in Bangladesh (Flanagan et al. 2012). The long latency period (8 to 14 years) for clinical manifestation of arsenicosis spreads fundamental confusion among the rural poor, who can hardly differentiate between leprosy and skin lesions caused by arsenic contamination (Alam et al., 2002; Khan & Yang, 2012). Besides, many arsenicosis patients remain undertreated in

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[2] https://sustainabledevelopment.un.org/content/documents/981bangladesh.pdf

[3] Report on "On the Post-2015 Development Agenda for Bangladesh" Retrieved from: http://www.un-bd.org/docs/Post%202015%20Agenda%20UNCT%20Report.pdf; accessed on October 22, 2014.

Bangladesh, due to people's lack of financial ability and absence of specific treatment (Chowdhury et al., 2006; Brinkel et al., 2009).

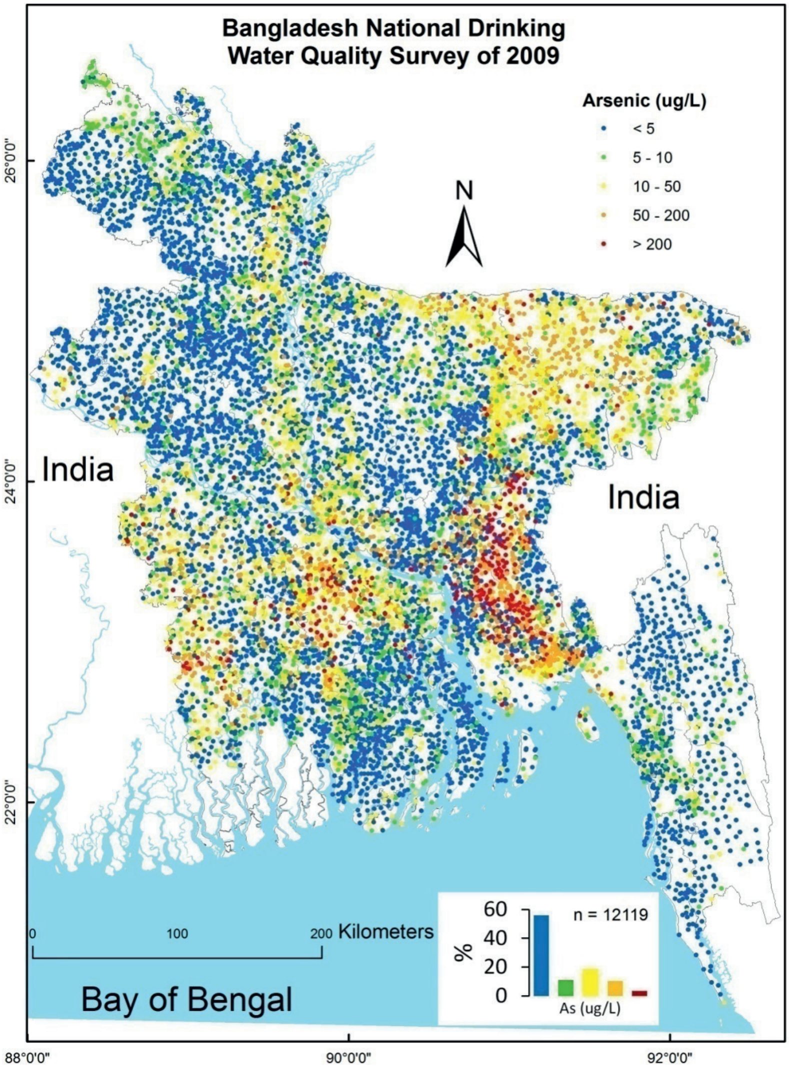

Figure 1.2: Extent and severity of arsenic contamination in Bangladesh (Bangladesh National Drinking Water Quality Survey of 2009)

Arsenic contamination has several social implications including isolating and ostracising the arsenicosis patients from social life (Paul & De, 2000; Nasreen, 2002; Hadi & Parveen, 2004; Hossain et al., 2005; Sultana, 2006). In many cases, people are reluctant to establish a marital relationship with patients and their family members (Chowdhury et al., 2006). The adult women (unmarried and married) are perhaps the worst victims as skin lesion is considered a major reason for issuing a divorce (Nasreen, 2002; Sultana, 2006). In addition, 'Arsenic orphans' refers to the children whose parents died of arsenicosis and who have become stigmatised as a result of the superstition that such people are cursed by God (Chowdhury et al., 2006).

1.1.3. Arsenic mitigation efforts

In order to mitigate the arsenic crisis, the Government of Bangladesh (GoB) with support from several non-state actors[4] adopted a National Arsenic Mitigation Policy followed by an Implementation Plan for Arsenic Mitigation (GoB, 2004a; GoB, 2004b) to provide a guideline and to speed up arsenic mitigation activities (Milton et al., 2012; Khan & Yang 2014). The Department of Public Health Engineering (DPHE), under the Ministry of Local Government and Rural Development and Cooperatives, has been assigned as the mandated agency to coordinate arsenic mitigation activities, and is also responsible for ensuring rural water supply in Bangladesh (Ahmed et al., 2006). According to DPHE, the mitigation approach includes four steps[5]: (i) screening and marking of safe versus unsafe shallow hand pump tube wells; (ii) awareness building; (iii) patient identification and management; and (iv) provision of arsenic-safe drinking water. During 2000-2003, about 4.94 million shallow hand pump tube wells were screened and 1.44 million were marked as contaminated by arsenic. Yet the status of millions of remaining shallow hand pump tube wells, including those newly installed after 2004, is yet to be known (Flanagan et al., 2012). Although there is no separate awareness building and patient management unit in DPHE, several NGOs and hospitals (public and private) are involved in providing such services.

1.1.4. Technological innovations for mitigating arsenic contamination

The provisioning of safe drinking water through development of arsenic mitigation technologies is a complex and expensive task (Escamilla et al., 2011; Milton et al., 2012; Johnston et al., 2014). With an effort of two decades, two categories of arsenic mitigation technologies have been developed and introduced in Bangladesh: first, alternative options to shallow-tube well water; and second, arsenic removal technologies that purify arsenic-contaminated shallow tube well water (Ahmed et al., 2006; Jakariya et al., 2007; Mahmud et al., 2007). The first category

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[4] World Bank, Dhaka Community Hospital, British Geological Survey (BGS), United Nation Children's Fund (UNICEF), World Health Organization (WHO), Japan International Cooperation Agency (JICA), Danish International Development Agency (DANIDA), Canadian International Development Agency (CIDA), International Development Enterprises (IDE), University of Dhaka, Bangladesh University of Engineering and Technology (BUET), BRAC, Asia Arsenic Network (AAN), etc.

[5] http://www.dphe.gov.bd/index.php?option=com_content&view=article&id=96&Itemid=104

includes the deep tube well, improved dug well, rainwater harvesting, piped water supply, and the pond sand filter. The second category consists of arsenic removal filter technologies, including, for example, the household-based Sono 45-25, MAGC/ Alcan media based technology, Read-F, Neelima, Swadesh and Sidko ADSORPAS Granular Ferric Hydroxide technology.

These arsenic mitigation technologies have been discussed by several authors (Ahmed, 2002; Alamet al., 2002; Ahmed et al., 2006; Milton et al., 2007; Kabir & Howard, 2007; DPHE & JICA, 2009; Hossain et al., 2015). The national arsenic mitigation policy and implementation plan for arsenic mitigation tends to privilege the installation of surface water technologies (for instance, improved dug well and pond sand filter). Despite this, non-contaminated ground water sources accessed through the deep tube well are promoted practically by DPHE (Johnston et al., 2014). As such, it is found that 84.4 percent of the arsenic mitigation technologies are deep tube wells, whereas the contribution of arsenic removal filters remains low (See Figure 1.3).

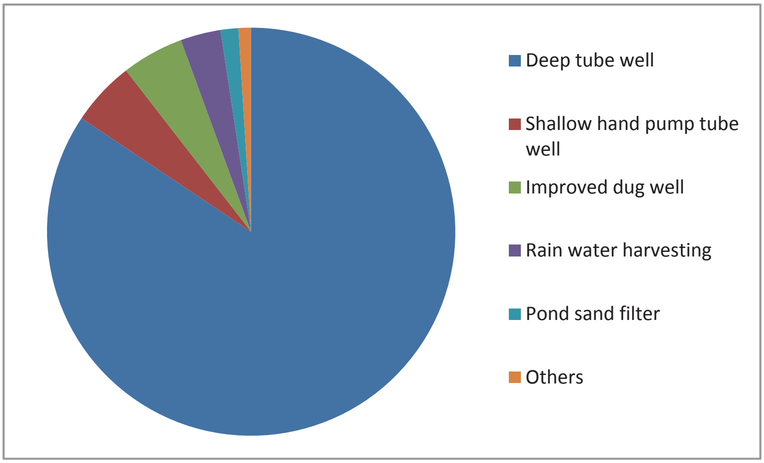

Figure 1.3: Arsenic mitigation technologies in rural Bangladesh (Ravenscroft et al., 2009; DPHE & JICA, 2009)

In sum, no single alternative safe water or arsenic mitigation technology has been widely developed or promoted (Milton et al., 2012), particularly one that would be suitable for all affected areas (GoB, 2009). Given that arsenic contamination of shallow tube well drinking water continues to challenge the hegemony of this mode of safe drinking water provision, this has generated incentives for development of new technological innovations (Sultana, 2013). As such, many experimental arsenic removal or alternative safe drinking water technologies have emerged, persisted and/or disappeared from the demonstration field over the last decades. In parallel, many rural people who do not have access to such options in contaminated areas still rely on contaminated shallow hand pump tube wells (Ahmad et al., 2006). Besides, a wide range of emerging (and some long-standing) arsenic mitigation technologies and/or safe drinking water options face challenges of social acceptability and widespread dissemination. This situation becomes more complicated by the fact that some of the most highly affected but remote areas (and their people) receive fewer mitigation technologies, which enhances the risk to be exposed to arsenic (DPHE & JICA, 2009).

This has generated a complex socio-technical challenge of how to provide safe drinking water to the rural population of Bangladesh. It is obvious that technologies bring changes in society, even as societal factors shape technological trajectories and choices (Geels, 2002). However, the *social determinants* of technological changes, including the dynamics between social actors, societal needs and desires, and social structures, are more or less neglected in the domain of arsenic mitigation technologies. Although significant progress has been made in national-level attempts to mitigate arsenic contamination, the success of arsenic mitigation technologies is still limited, indicating the necessity of considering the societal context for technological development and uptake, in securing safe drinking water in a post-arsenic phase (Johnston et al., 2014; Hossain et al., 2015). This thesis addresses this pressing need and associated research gaps, as further elaborated below.

1.1.5. Research gap

Extensive research has been carried out in the domain of arsenic contamination of drinking water, including in Bangladesh, yet the focus has remained predominantly on technical issues relating to engineering, hydrogeology, geomorphology and microbiology (van Geen et al., 2003; Ravenscroft et al., 2009; Chakrabortiet al., 2010; Hossain et al., 2015; Brinkel et al., 2009). It is clear, however, that the success of arsenic mitigation technologies and the stability of the safe drinking water sector require contributions from technical *and* social sciences (Johnston et al., 2014; Hossain et al., 2015).

Where social aspects have been studied, one aspect is emphasized: studying the dynamics of *social acceptability* of arsenic mitigation technologies. Social acceptability is often seen as a crucial ingredient in the success and failure of technological interventions in the safe drinking water sector (Hoque et al., 2004; Kabir & Howard 2007; Johnston et al., 2010; Mosler et al., 2010; Inauen et al., 2013; Hossain & Inauen, 2014). Yet, in the existing literature on social acceptability, the conceptualization of acceptability as understood by experts still dominates, even as the important (end-) user perspective on acceptability remains understudied.

A focus on factors shaping social acceptability from an expert perspective does not however fully consider a technology's context of development and implementation and its interactions with the broader societal context of safe drinking water provision and use. One key gap to be filled is to analyze social acceptability through focusing on user perspectives on acceptability and understanding how these might differ from expert perspectives. Furthermore, social acceptability of given technological interventions in only one piece of the larger puzzle of tacking the safe drinking water provision challenge. Going beyond this, understanding the reasons why a specific technological innovation becomes dominant, and when and how certain innovations start to occupy a technological niche, from which they can be scaled up, requires going beyond a social acceptability analysis (whether from an expert or user perspective). Yet the existing literature is inadequate for understanding the successes and failures of socio-technical changes in the safe drinking water sector in the context of arsenic mitigation, particularly in developing countries, and new conceptual approaches are needed.

1.2. Research objective and research questions

This thesis is part of a larger project funded by the Netherlands Organization for Scientific Research Foundation for Scientific Research of the Tropics and Developing Countries on socio-technical changes in the safe drinking water regime of rural Bangladesh. The central research objective of this thesis is to understand the success and failure of socio-technical changes to the safe drinking water sector in rural Bangladesh in the post-arsenic contamination phase. In order to understand the success and failure of socio-technical changes, several issues need to be explored, including how users conceptualize social acceptability of specific arsenic safe options, how and why a specific technological innovation becomes dominant, how and why emerging technologies fail (to some extent) to contribute to mitigating the arsenic crisis, and how real world experiments with emerging novel technologies can be successfully developed and diffused in society.

Therefore, to further the research objective, the following four specific research questions are addressed, each of which corresponds to one empirical chapter of this thesis:

i) How do users understand social acceptability of three prominent arsenic mitigation technologies (deep tube well, improved dug well and the arsenic removal household Sono filter)?
ii) Why and how has a technological innovation (the deep tube well) become dominant in the context of arsenic contamination?
iii) How and why did the promising take-off of the household arsenic removal Sono filter stagnate, and what conditions shape its potential diffusion and uptake?
iv) How do novel experimental technologies (such as the Sub-Surface Arsenic Removal) function as emerging socio-technical experiments in rural Bangladesh, and (how) can they re-stabilize the existing safe drinking water regime?

In furthering the research objective through addressing these four sub-questions, this thesis develops an analytical framework through which to study these different aspects of socio-technical changes in the safe drinking water regime in rural Bangladesh. This framework also guides the methodology and data generation and analysis undertaken in this research.

1.3. Conceptual framework

Constantly, new technological innovations are developed. They often co-exist with old ones, and only a few technological innovations become dominant and contribute to solving problems, as defined by social actors. Technological innovations area driving force that triggers societal changes and vice-versa, thus technology-society interaction and socio-technical changes have become a core concern of the field of Science and Technology Studies, with a key postulate being that technical and social domains are closely intertwined and thus co-evolve rather than being two distinct entities (Hegger, 2007; Reeger & Bunders, 2009; Hegger & van Vliet, 2010).

Several schools of thoughts have developed to theorise socio-technological changes. One early school of thought can be characterized as technological determinism, insofar as it assumed that technology development was autonomous and had a linear influence on society (see Mol, 1991 for an elaboration and critique of this perspective). This ‘technology-push’ approach was criticised for neglecting the non-technological aspects of socio-technical change, such as social, political, economic, cultural, and regulatory forces that influence the direction of technology development. In contrast, a ‘demand-pull’ approach, as developed, for example, by Kondratiev, emphasizes economic determinants of technological change, which has been criticised for its techno-economic deterministic nature (van Duijn, 1977; Mol, 1991).

Next to these two approaches, the concepts of a “technological regime” and “technological paradigm”[6]—where variation and selection of technologies takes place—have appeared, in order to include socio-cultural and political aspects of technological development. According to these concepts, technological development is the result of evolutionary processes of variation and selection in society (Dosi, 1982; Nelson & Winter, 1982). These ideas have been partially criticized for their emphasis on technology as an autonomous or quasi-autonomous factor shaping societal change (Mol, 1991). In contrast, social constructivism emphasizes the economic and socio-cultural embeddedness of technological change, which was neglected in previous approaches. The main argument behind a social constructivist perspective is that technological innovation is socially constructed, as a means to achieve wider societal change and that it follows a multi-linear development path (Hughes, 1986).

Within this perspective, several theories have been developed including the Social Construction of Technology (SCOT), the Large Technical System and the Actor Network Theory (ANT). According to SCOT, relevant social groups are key to developing technological innovations by formulating different interpretations or meanings of the problem to be addressed. ‘Stabilization’ takes place when a given technological innovation offers a solution to a perceived problem. ‘Closure’ of technological innovations happens as a result of such stabilization (Pinch & Bijker, 1984; Bijker et al., 1987; Klein & Kleinman, 2002). Despite SCOT’s usefulness in explaining societally informed processes of technological development, it has been criticized for

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[6] The concept of paradigm was coined by Thomas Kuhn (1962).

emphasizing agency of actors while ignoring structural factors influencing societal changes (Mol, 1991; Bijker, 1995; Klein & Kleinman, 2002).

In parallel to SCOT, perspectives such as Large Technical System have emerged to affirm that the forces that lead to technological change are internal to any given large technological system. A Large Technical system consists of a complex physical structure and a similarly complex social network of actors and institutions to manage the technical system (Hughes, 1986; Mol, 1991). Although this can explain changes already taking place (on not), it lacks analytical and conceptual power to recognize the necessary conditions and mechanisms for future technological system change (van Vliet, 2002). On the other hand, Actor Network Theory was developed with an aim to put symmetric attention on actors, artefacts and systems, without making any fundamental distinction between them (Callon, 1987). The criticism of actor network theory is that it remains overly descriptive and cannot provide explanations for social processes of change, inherent to technological development (Amsterdamska, 1990). This criticism forms a background against which the alternative perspectives, including Technological Innovation System theory and Transition Theory have emerged, which this thesis leverages in developing its analytical framework to greater extent.

Technological Innovation System analysis is a heuristic framework that aims to understands the prospects and dynamics of a particular technological innovation and its successful diffusion (Carlsson & Stankiewics, 1991; Twomey & Gaziulusoy, 2014). Practically, Technological Innovation System analysis has been used to analyse emerging innovations at an industry level by paying attention to the arrangement of social structures and activities (Smith et al., 2010). The criticism of Technological Innovation System includes: (i) the marginalisation of cultural and economic aspects; (ii) lack of explanation of the dynamics whereby a dominant technology is replaced; (iii) a focus on functions rather than system changes; and (iv) neglect of the actors and institutions at grass root levels (Smith et al., 2010).

Supplementing this, therefore, transition theory draws upon a complex mix of evolutionary economics, sociology of technology, and history of technology (Geels & Kemp, 2007). This overarching perspective on sociotechnical change consists of a number of elements or sub-components, including Multi-level Perspective, Transition Management and Strategic Niche Management theories. It is concerned with explaining, most broadly, how transitions take place in socio-technical systems. The notion of transition refers to long-standing changes caused by a dynamic interaction between technical, social, economic, cultural, institutional and regulatory domains (Rotmans et al., 2001).

Among its key elements, Multi-level Perspective (MLP) is a middle-range theory[7] and a heuristic framework that focuses on analysing the prospects and dynamics of broader socio-technical

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[7] Merton (1968) introduced the term of middle-range theory to steer the extremes of grand theory and grounded theory (abstracted empiricism)(Geels, 2011).

transitions that include a variety of technological innovations in the context of transformative societal processes (Rip & Kemp, 1998; Geels, 2002; Geels, 2005). Even though early research in this tradition focused on explaining historical transitions, the multilevel perspective also seems useful in explaining ongoing socio-technical changes. Such changes are studied here as the outcome of interactions between three levels (of analysis): the landscape, socio-technical regime, and niche levels (Rip & Kemp, 1998; Geels, 2005; Geels, 2011). A landscape (macro level) encompasses deep environmental, natural, economic and political phenomena that are rather stable and provide the context for bringing change in socio-technical regimes (Geels, 2004). A socio-technical regime (meso level) refers to a stable configuration of seven interrelated dimensions (technology, users' preference, application domain, symbolic meaning, infrastructure, industry structures and policies, etc.), which is difficult to influence by the actors (Rip & Kemp, 1998; Schot, 1998; Geels, 2004). A niche (micro level) entails a space where actors experiment with radical innovations that may bring changes to the prevailing regime (Kemp et al., 1998). Besides, several change mechanisms —reproduction, transformation, and transition—in the socio-technical system can also be recognized and analysed (Geels & Kemp, 2007).

Complementing the multilevel perspective, Transition Management as an aspect of transition theory has a more governance—and policy—related focus, and a concern with supporting radical and system innovation. Transition management refers to the reflective variations of societal dynamics in order to navigate society into a preferred direction (Hegger, 2007). This framework has been criticised for putting undue emphasis on central actors, instead of on a wide range of social actors involved in the innovation process (Kemp & Loorbach, 2003).

Strategic Niche Management, as another aspect of transition theory, highlights the importance of protected spaces for radical innovations with the aim to craft and analyse the success of niche innovations to penetrate the prevailing regime (Kemp et al., 1998). In particular, the success of niche development relies on its three dimensions: network building, the shaping of expectations and facilitating learning (Geels & Schot, 2007). Although Strategic Niche Management is useful in analysing the prospect (or not) of establishing and further developing niche technologies, its limitation to explain real world experiments with emerging technologies is recognized. By giving a more crucial role to the real world experiments with experimental technologies, the concept of 'socio-technical experiments' has emerged to explain the potential of novel experimental technologies to be tested, and their prospects for niche formation and scaling-up (Ceschin, 2014). These aspects of transition theory are depicted in Figure 1.4 below.

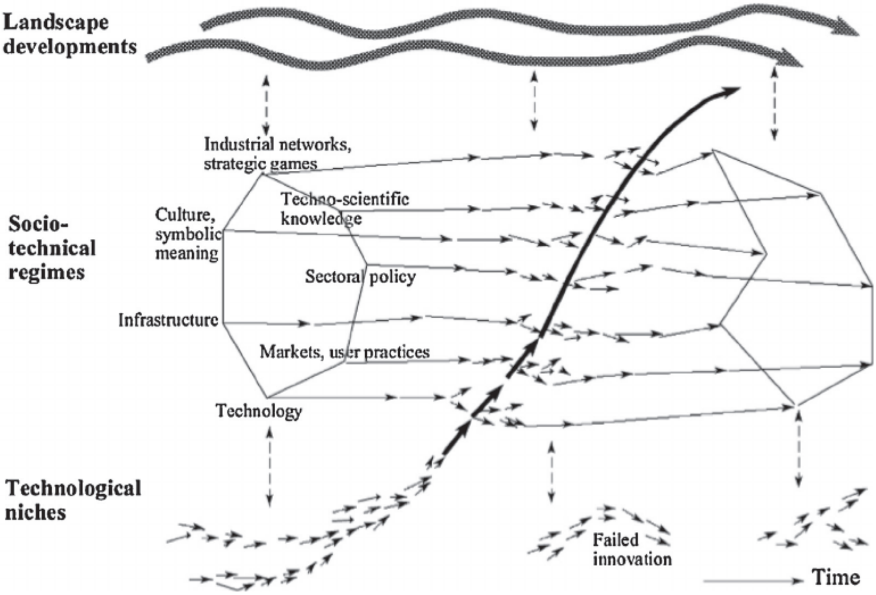

Figure 1.4: Conceptual framework: Multi level perspective on socio-technical transitions (Source: Geels, 2002: 1263).

In accordance with the research questions, this thesis proceeds in four steps to analyze socio-technical regime changes in rural Bangladesh, in the context of arsenic contamination. It assesses, first, how users (rather than experts) conceptualize social acceptability and factors shaping acceptability of diverse arsenic mitigation technologies, from the user perspective (Chapter 2). By using the Multilevel Perspective, I next deploy the concept of the socio-technical regime (and its seven dimensions) to explain the dominance of a given technological innovation, in this case the deep tube well (Chapter 3). This is followed by an analysis of the conditions under which a radical innovation, such as a household filter can establish a technological niche prior to up-scaling (Chapter 4). In this chapter, three dimensions of niche formation (actor networks, expectations, and learning) are explored to show how radical innovation struggles at the niche level against the existing socio-technical regime. As a final step, I explore the concept of socio-technical experiment, to assess conditions that experimental technologies need to fulfill in the pre-niche period, in order to subsequently occupy a technological niche and potentially scale up. In particular, three such functions are explored in detail: whether the experiment can function as a living lab, a window and an agent of change (Chapter 5).

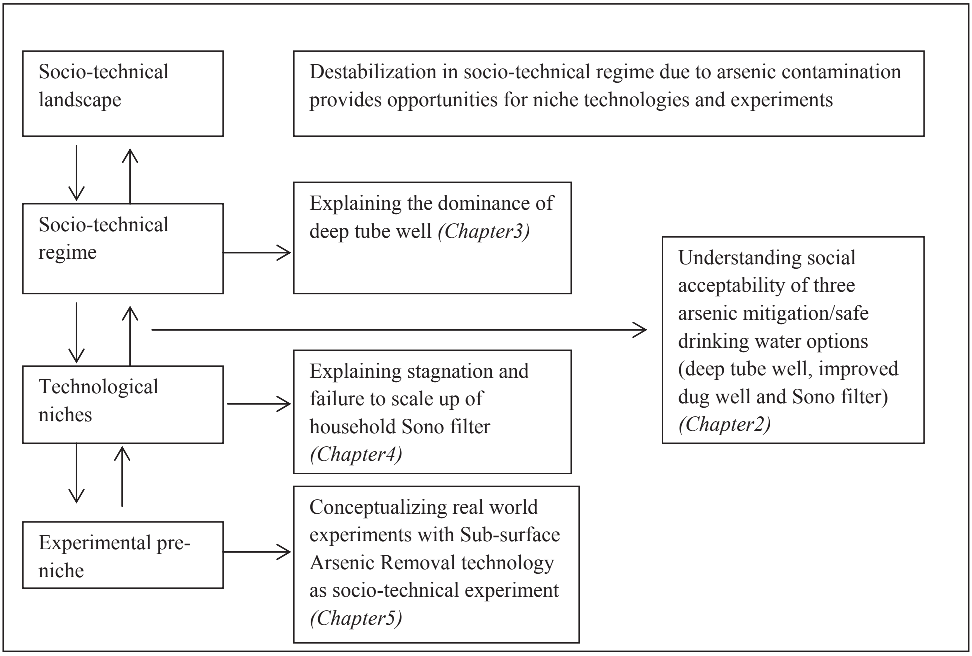

Figure 1.5: Analytical lens on the socio-technical safe drinking water regime in rural Bangladesh

1.4. Methodology and approaches

The section explains the research design and methods, paying special attention to criteria for selecting the four technological innovations analysed in this study, as well as providing information on the study areas, data collection techniques and analytical methods. The section concludes with discussing issues of internal and external validity.

1.4.1. Research design

As research design, a case study approach is used. It is widely argued that the case study approach seems to be effective in dealing with a descriptive question (What happened?) and an explanatory question (How and why does something happen? To what extent has it happened?) (Yin, 1993; Yin, 1998). As this thesis deals with such types of questions, this study considers the case study as an effective approach to investigate the research questions. According to Yin (1993), a major rationale for using case studies is to be able to deal both with a particular *phenomenon* (like technological innovations for the provision of safe drinking water) and the *context* (like arsenic contamination) within which the phenomenon is occurring. Furthermore, the context is assumed to contain important explanatory information about the phenomenon, hence there is no clear boundary between phenomenon and context. A case study research is suitable to such research and can include qualitative and quantitative research methods, as well as rely on multiple sources of evidence and benefit from the prior development of theoretical propositions. In this thesis, the theories of multi-level perspective, strategic niche management, and socio-technical experiment have guided the empirical research design in two ways: i) types of information that needs to be collected; and ii) generalizations that can be made from the information.

With regard to case study selection, criteria relating to emergence, development and dissemination (or not) of the four technological innovations were key. The four technological innovations differ in terms of stages of development, types, the scale of use, actors involved, and contribution to re-stabilizing the drinking water sector. This diversity was reflected in the case selection. The purpose of using this approach is to explore the influence of context on development of technological innovations that are being incorporated into society to bring about wider societal change. As such, this approach provides useful insights to understand the success or failure of socio-technical changes.

The first two technologies studied in depth in this thesis are the options to rely on alternatives to arsenic removals technologies, hence they are not linked to treatment of arsenic contaminated water. These include the deep tube well (84.4 percent of total installed arsenic mitigation options in Bangladesh) and improved dug well (given that surface water is prioritized within the National Arsenic Mitigation Policy). The second category includes arsenic filter technologies that purify arsenic contaminated water: Sono filter (as an example of household-level arsenic removal filter) and sub-surface arsenic removal (SAR) technology (as an example of community-level arsenic removal filter under experiment). A detailed description of these four technological innovations is provided in Chapters 2, 3, 4 and 5.

1.4.2. Data collection and data analysis

A case study approach provides an in-depth analysis through the use of both qualitative and quantitative data collection tools, including in-depth interviews, surveys, observations, focus group discussions and document analyses (See Table 1.1). Similarly, various actors (persons and institutions) and processes related to a case can be investigated under a given context.

As the possibility of studying all four technologies over the entire country of Bangladesh or in one single district was limited, this study picked five separate areas (villages and unions) from four districts (See Figure 1.4 for study area). The reasons behind selecting these areas were (a) the prevalence of arsenic contamination; and (b) availability of the technological innovations. As such, Uttar Suchipara Union (lowest administrative unit of local government) of Chandpur, an east-central district of Bangladesh, was selected for the analysis of the dominance of the deep tube well. On the other hand, Sono filter was available in Mokarimpur Union of Kushtia, a north-western district, whereas improved dug well was available in Shimuliya and Baliakhora Unions of Manikganj, a central district. In addition, the experiments with SAR technology were carried out in two different villages of Comilla and Manikganj districts.

Table 1.1: Overview of data collection methods

Methods	Chapter in which method is used	Strategy used
In-depth interviews	Chapters 2, 3, 4 and 5	Face-to-face interviews were tape-recorded, translated and transcribed
Focus group discussions	Chapters 2, 3, 4 and 5	Discussions were tape-recorded, translated and transcribed
Questionnaire surveys	Chapters 3 and 5	Individual discussions with users from household and questionnaires were filled out for analysis
Workshops	Chapters 3 and 4	With key stakeholders
Consultation meetings	Chapter 5	Regarding experiment with community and potential users
Observation	Chapters 5	Activities of implementation are documented
Informal discussions	Chapters 5	Informal talks
Archival documents	Chapters 2, 3, 4 and 5	Regarding arsenic mitigation technologies, GOs and NGOs reports, meeting minutes

In order to generate information on the success and failure of socio-technical changes, primary and secondary data were collected. To obtain qualitative and quantitative primary data, several tools were used (see Table 1.1). Qualitative data was collected from actors related to the development and dissemination of particular technological innovations, using focus group discussions, in-depth interviews, workshops, consultation meetings, observation and informal discussions. Quantitative data was collected from the users using two semi-structured survey questionnaires. The total number of respondents against data collection tools is presented in Table 1.2. Furthermore, a number of secondary sources, including archives of the government and NGOs, websites, journals, policy reports and minutes of the meetings have been used. The empirical chapters (2-5) and appendixes contain the details of data collection, including the instruments and respondents of surveys, in-depth interviews and focus group discussions.

Table 1.2: Total number of respondents against data collection tools

Data collection tools	Numbers/respondents
Surveys	Two with 233 households
In-depth interviews	140 respondents
Focus group discussions	32 FGDs with 198 respondents
Consultation meeting	Six meetings where 97 respondents participated
Workshop	Two where 30 respondents participated

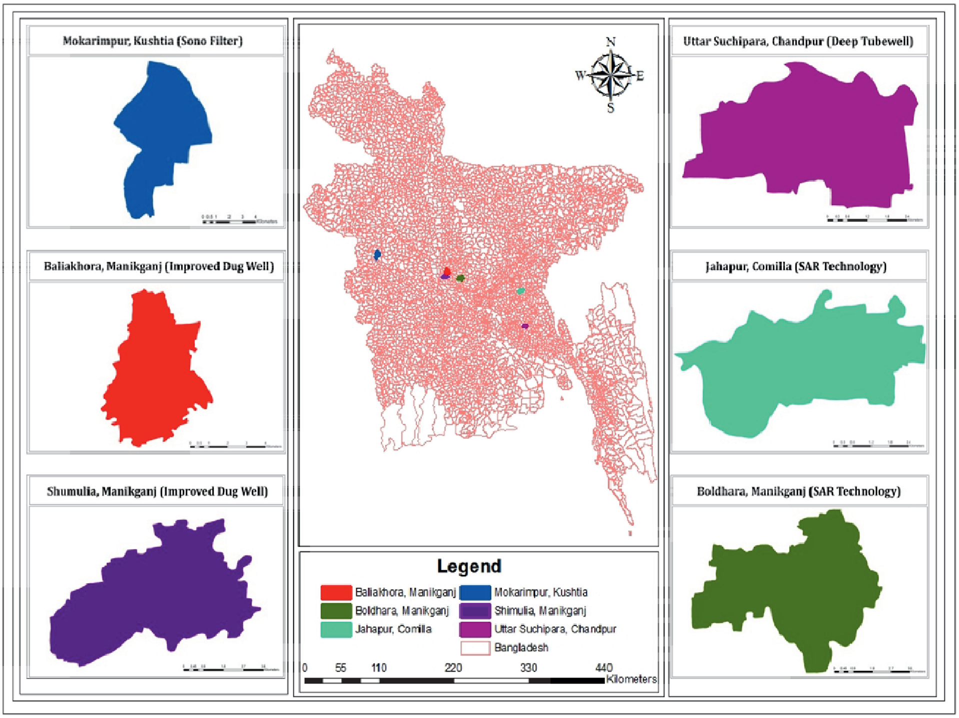

Figure 1.6: Study areas

1.4.3. Internal and external validity

Validity refers to the accuracy and generalizability of the findings and can be divided in two categories: internal and external. Internal validity refers whether findings are a true reflection or representation of reality; whereas external validity refers to the generalizability of context-specific representations of reality (Denzen 1970; Brink 1993; Golafshani 2003; Creswell, 2014). Although perfect validation is virtually impossible to achieve (Neuman, 1997), the necessity of seeking validity in research is important (Green and Hert, 1999). There are many ways of increasing internal and external validity of the research and its findings.

With regard to internal validity, this research was designed to reducefour major sources of errors connected to: i) the researcher and the team; ii) subjects participating in the project; iii) the situation or social context; and iv) the methods of data collection and analysis (Brink 1993). In order to increase internal validity, both qualitative and quantitative data were triangulated through using multiple data collection tools (for example, focus group discussion, survey, in-depth interviews, observation etc.) in the study. The purpose of triangulation was not only to cross-validate data through using several data collection techniques but also to capture diverse dimensions of the same topic. During data analysis, several analytical techniques (thematic and schematic analysis of quotations, facts, and content, etc.) were applied to grasp diverse dimensions of socio-technical changes. However, triangulation is not enough to ensure validity. Reliability of data also strengths internal validity. Reliability refers to the consistency, stability and repeatability of data (Selltiz et al., 1976). For the purpose of ensuring reliable data, investigators and observers play an important role in collecting information from the informants. Besides, reliability usually depends on the extent to which observers can cross-check information. Practically it refers to dependability and confirm ability (Brink 1993). In order to ensure reliability of data, interviews were recorded either in audio or written format. In case of observation, processes were followed in a systematic way. Furthermore, local workshops with multiple stakeholders and meetings with experts were run to verify the accuracy of the data.

In addition, the researcher's participant involvement in implementing the project (for example, being part of the research team executing the socio-technical experiment with sub-surface arsenic removal technology) helped to deepen the understanding of diverse realities associated with sociotechnical changes. Due to the dual role of the researcher as participant and observer, access to diverse perceptions of reality through interaction with participants and respondents was facilitated. In addition, area-wise differences in socio-technical settings helped the researcher to cross-check facts. As mentioned earlier, several techniques (i.e., survey, focus group discussions, interviews and observation) were deployed for triangulations during the data collection process. In doing so, respondents were adequately informed, trust-relationship was ensured. Moreover, the same respondents were interviewed on several occasions and similar information was gathered from multiple sources. Peers' and experts' consultations were another strategy to enhance internal validity. Another way to guarantee the internal validity is to spend prolonged period of time in the field of the thesis during data collection. Data for the first three empirical chapters (Chapter 2, 3 and 4) was collected during 2011-2013, whereas the data for fourth empirical paper was collected during 2013-2014. Even after data collection, as several changes were taking place during sociotechnical experiment with SAR, the researcher had direct contact with the caretaker of the SAR technology to follow up the project. In addition, several working drafts and works in progress were presented in project meetings, seminars, summer schools, and international conferences, which led to extensive formal and informal peer review of findings.

To ensure external validity, case selection within this study aimed to provide a fair representation of the diverse array of alternative safe drinking water and arsenic removal technologies that emerged, were experimented with, implemented and disseminated for addressing the problem of arsenic contamination of drinking water in rural Bangladesh. As explained above, special attention has also been paid in selection of cases along with its relation to actors, implementing agencies, and the process of dissemination. As the broad objective of the thesis is to generate in-depth insights on the success and failure of socio-technical changes, the selection of the four arsenic mitigation options provides a general contextual scenario of the phenomena. Apart from this, in ensuring external validity, the thesis also deals with the extent to which transition theory is applicable in a developing country context. Under the purview of transition theory, this thesis applies the multilevel perspective and related concepts (for example, social acceptability, niche management, sociotechnical experiments and scaling up etc.) to develop conceptual frameworks. While applying these conceptual frameworks, this thesis examines if new theoretical insights within transition theory are possible. In addition, this thesis highlights how the findings can be effective for other areas where transition theory might be applied. The aim was to be able to contribute both to theoretical and empirical knowledge that is generalizable beyond this specific context of rural Bangladesh and beyond the specific sociotechnical challenge of arsenic mitigation of drinking water. How this study does so is elaborated further in the conclusion.

1.5. Outline of the thesis

This thesis is organized into six chapters including this introductory chapter (Figure 1.5). This chapter offers a broader picture of what has so far been studied in this field to find out the research gap, which further provides the rationale for conducting a new research that will contribute both theoretically and empirically. In addition, the methodological approach precisely introduces the study locations, data collection activities, and data analysis.

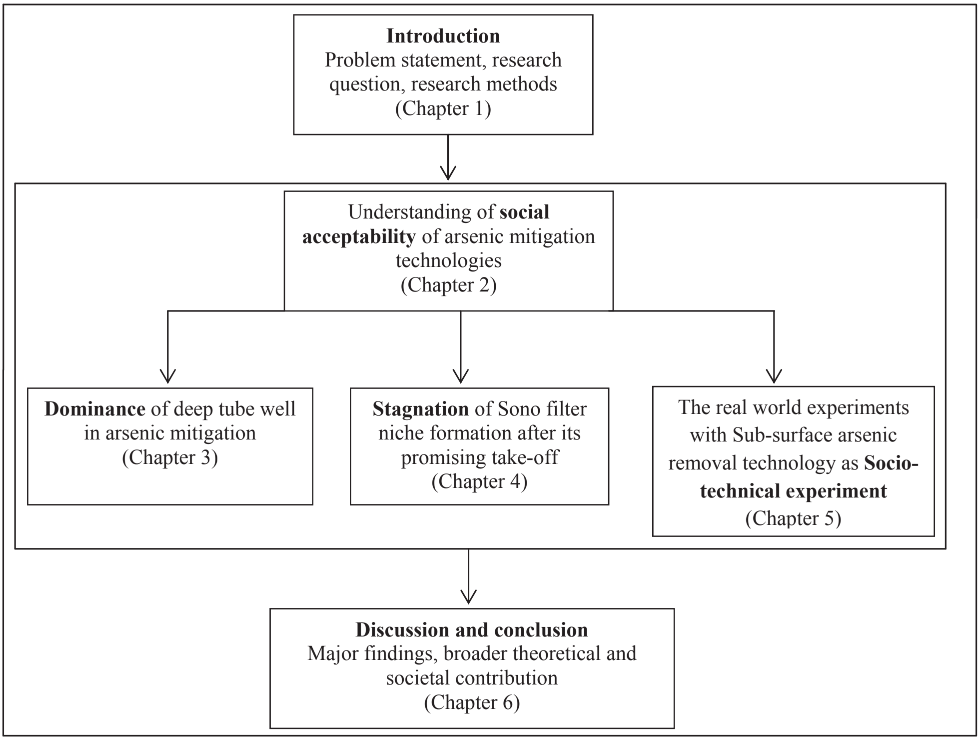

Figure 1.7: Interconnectedness between the chapters

Chapters 2, 3, 4 and 5 present the empirical findings of this thesis based on the above mentioned theoretical framework and methodological approaches. Chapter 2 presents a qualitative framework on how users frame and understand social acceptability of three arsenic mitigation technologies. Chapter 3 investigates why and how a technological innovation designed to provide safe drinking water in the context of arsenic contamination has become dominant. Chapter 4 explores how and why the promising take-off of the Sono filter stagnated, and what is to be said about the possibility of its further diffusion and uptake. Then Chapter 5 analyses whether and to what extent has the real world experiment with Sub-surface arsenic removal (SAR) technology functioned as a socio-technical experiment and the consequences for niche development and scaling-up. Finally, Chapter 6 reflects on the overall socio-technical changes that have been taking place in the drinking water sector after arsenic contamination by studying the case studies of four different technological innovations in the earlier chapters (2-5). This chapter also provides theoretical and empirical implications of the study and draws insights on a direction for future research and policy recommendations.

Chapter 2

Understanding social acceptability of arsenic safe technologies in rural Bangladesh: A user-oriented analysis

This chapter has been published as:

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Abstract

Contamination of shallow tube well drinking water by naturally occurring arsenic is a severe societal and human health challenge in Bangladesh. Multiple technological interventions seeking to ameliorate the problem face hurdles in securing *social acceptance,* i.e. a willingness of users to receive and use a technology. While most articles focus on expert understandings of social acceptability, this article analyses how users themselves understand the factors shaping social acceptability of safe drinking water options in rural Bangladesh. We then deploy such understandings to comparatively assess which factors users see as most important in securing social acceptance of three safe drinking water options in rural Bangladesh: the arsenic removal household (Sono) filter; the deep tube well, and improved dug well. We draw on focus groups and semi-structured interviews with technology users in six villages across three districts to analyze how users assess the social acceptability of specific arsenic safe technologies. Our findings highlight that factors such as availability, affordability and compatibility with existing water use practices, as understood by users, are key to securing their acceptance of a specific arsenic safe option. In concluding, we point to a future research agenda in analyzing user-oriented social acceptability of arsenic safe technologies in developing country contexts.

2.1 Introduction

Arsenic contamination of shallow tube well drinking water in Bangladesh is an urgent developmental and health challenge (Sekar & Randhir, 2009). Arsenic in groundwater is naturally occurring in Bangladesh, yet it severely limits access to safe drinking water for the rural poor, who are most reliant on shallow hand pump tube wells as their main source of drinking water (Atkins et al., 2007; Chakraborti et al., 2010; van Halem et al., 2010; Rammelt et al., 2014). The problem has its origins in a well-intentioned bid in the early 1970s by the Government of Bangladesh and the United Nations Children’s Fund (UNICEF) to address the problem of contaminated surface water and provide the rural population with an alternative source of safe drinking water. An estimated ten million shallow tube wells were installed in rural households in Bangladesh to ensure a continuous supply of safe drinking water (van Geen et al., 2003). Initially, this ensured access to safe drinking water for 97% of the population, an impressive achievement (Smith et al., 2000). However, this rate dropped to 72% by the early 1990s, following the detection of naturally occurring arsenic in ground water (Mahmud et al., 2007; Johnston et al., 2010; UNICEF, 2010).

Exposure to arsenic contaminated water can result not only in arsenicosis, which refers to a wide range of diseases from skin lesions to cancer, but also to an array of social problems (Nasreen 2002; Hassan et al. 2005). Depending on what arsenic threshold levels[8] are considered, an estimated 30-56.7 million people are currently exposed to arsenic contaminated drinking water in Bangladesh (DPHE & JICA, 2009; Milton et al., 2012). In response to what has been termed the “biggest mass poisoning” in history (WHO, 2000), the Government of Bangladesh developed the *National Policy for Arsenic Mitigation* in 2004, followed by an implementation plan to address the crisis (GoB, 2004a, 2004b). Over the last decade, various arsenic mitigation technologies and safe alternative drinking water options have been tested and disseminated in Bangladesh. These options can be grouped into two categories: (i) filter and treatment technologies that remove arsenic from contaminated shallow tube well water, such as household and community-level filter systems; and (ii) alternative safe water options, such as piped water supply, deep tube wells, improved dug wells, safe shallow hand pump tube wells and rain water harvesting (Hoque et al., 2004; Ahmad et al., 2006; Inauen et al., 2013). Although a wide array of such options have been tested and deployed, exposure of the rural population to arsenic remains high. Although these technologies and interventions can be efficacious in removing arsenic from drinking water or providing safe drinking water alternatives, research has consistently shown that many face hurdles in securing *social acceptability* (Mahmud et al., 2007; Shafiquzzaman et al., 2009; Johnston et al., 2010; Mosler et al., 2010).

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[8] 30 million people are exposed to arsenic contamination by consuming more arsenic in drinking water than the Bangladeshi safety limit of 0.05 mg/L, whereas 56.7 million people are at risk, according to the World Health Organization guideline value of 0.01 mg/L.

In this paper, we thus analyze how users of three arsenic safe technologies understand social acceptability. The three technologies we focus on include: a household arsenic removal filter system (the Sono filter) and two community-level alternative water provisioning technologies (a deep tube well and an improved dug well). In analyzing social acceptability of these three arsenic safe technologies, our first key aim is to go beyond expert notions of social acceptability to delineate how users themselves understand and prioritize factors that shape social acceptability. Second, we draw on such user understandings to investigate the relative acceptability of each technological option for users.

We proceed as follows: the next section presents our research approach and methodology. We then distill from the literature a set of factors that may contribute to social acceptability of risk reducing technologies, in order to then investigate how such factors are understood by arsenic-safe technology users in Bangladesh. We next analyze the importance that users attach to each of the identified factors in securing acceptance (or not) of a given technology. We conclude by synthesizing and explaining the relative social acceptability for users of the three technologies in our study area, as revealed by our analysis.

2.2. Methodology and approach

This section explains our rationale for selecting the three technologies, the study areas, data collection techniques and analytical methods. As noted above, we selected three arsenic safe technologies from the two categories noted above: deep tube well (70% of total installed arsenic mitigation options in Bangladesh) and improved dug well (given that surface water is prioritized within national arsenic mitigation policy), as two safe water alternatives, and the Sono filter, as an example of a household arsenic removal filter technology. A deep tube well (with a so-called force-mode Tara-Dev pump or suction-mode UNICEF Number 6 pump) is a community-level drilled well, generally more than 150-metres deep. The improved dug well is a community-level technology that combines a protected dug hole with a water-lifting device like a UNICEF Number 6 hand pump (see appendix 1 for photographs of all three technologies). One improved dug well and one deep tube well usually serve ±10 households in the study areas. The Sono filter is designed to serve a single household by treating arsenic contaminated water obtained from a shallow hand pump tube well. It consists of two small plastic buckets, a filter media, flow controller, charcoal, river sand, brick chips inside and an iron stand as base. The cost of the Sono filter ranges from US$35 to US$65, whereas one-time installation costs for a deep tube well (US$ 1000) and improved dug well (US$ 900) are higher (Johnston et al., 2010; Ravenscroft et al., 2014). In the study areas, the provision of all three technologies were highly subsidized by the implementing agencies (the Department of Public Health Engineering or NGOs), who financed 90-95% of the total installation costs. In addition to the remaining installation costs, users were responsible to cover 100 percent of the operation and maintenance costs.

As the possibility of studying all three technologies in a single area was limited, we deliberately picked six villages from three districts (2 villages per district) where arsenic contamination levels are moderately high to very high, and hence where these technologies are being deployed. In Uttar Suchipara and Daikamta, two villages in Chandpur district, where 96-97 percent of existing shallow tube wells were contaminated, the Department of Public Health Engineering (DPHE) has installed community-level deep tube wells since 2009. Manob Sakti Unnayan Kendro (MSUK), a local NGO, has deployed Sono arsenic filters since 2009 in Nawda Khemirdiar and Islampur villages of Kushtia district, where 60-84 percent of the tube wells were contaminated. The local NGO Socio Economic Development Agency (SEDA) has deployed improved dug wells since 2008 in Shimulia and Pukhuria villages in Manikganj District, where 64-81% of the tube wells were contaminated (see Table 2.1).

In order to generate data on how rural users understand the factors shaping (their) acceptability of various arsenic safe technologies, we organized nine focus group sessions (two with female and one with male users, per technology). Hence, in total 90 users participated in focus groups (each of the 9 sessions consisted of 10 users, thus a total of 30 users per technology). Two focus group sessions were held in the villages of Islampur, Uttar Suchipara and Shimulia (one each with male and female users per technology), while one focus group session with female users was held in each of the villages of Nawda Khemirdiar, Doikamta and Pukhuria (see Table 2.1). We focused more on female users because of their leading role in domestic water management. Generally, a housewife or household head (usually male) was invited from one household to participate in a focus group session. A total of 19 households refused to participate in the sessions and were replaced by others. We were not able to detect any systematic bias (age, religion, income) in those refusing participation. In addition to focus groups, 21 in-depth interviews were conducted with users to gain further insight into aspects shaping their acceptability of the technologies. It should be noted that users participating in focus group sessions and in-depth interviews discussed only the specific technology they had been using.

Table 2.1: Field research data

Technology	**District**	**Villages**	**No. of focus groups**	**Total participants**		**Implementing agency**
				Female	**Male**	
Deep tube well	Chandpur	Uttar Suchipara	2	10	10	Department of Public Health & Engineering
		Daikamta	1	10		
Sono filter	Kushtia	Nawda Khemirdiar	1	10		Manob Sakti Unnayan Kendro (NGO)
		Islampur	2	10	10	
Improved dug well	Manikganj	Shimulia	2	10	10	Socio Economic Development Agency (NGO)
		Pukhuria	1	10		

Using data from focus groups, we compiled user understandings of a variety of factors assumed to shape social acceptability. Furthermore, we combined user interpretations of any given factor, regardless of which technology they were speaking about; we only distinguished between technologies if the three different technology user groups framed a given factor differently. As we elaborate in the next section, the factors we focused on were availability, ease of use, and affordability of the technologies; as well as user views on arsenic risk and water quality, and their current water use practices.

Subsequently, after focus group discussions, all users were asked individually to identify those factors they considered most important in shaping (their) acceptability of the technologies. Finally, they were asked to assess the overall acceptability of the technology they were currently using, and the reasons for their assessment. The average duration of each focus group (with 10 participants each) was two and half hours, and in-depth interviews lasted an hour. Furthermore, we collected data from secondary sources, including scientific journals, policy reports and media.

2.3. Social acceptability: a user's framework

2.3.1. Conceptualizing social acceptability: definitions and factors

A growing body of research in the fields of sociology, psychology and risk analysis has focused in recent years on identifying factors that shape social acceptability of risk reducing technologies. This includes studies relating to arsenic contamination of water as well (Chakrabortiet al., 2010). Generally, how experts conceptualize the factors shaping social acceptability have tended to dominate existing social science analyses. A few studies have assessed the most preferable arsenic safe option based on users' perspectives (see Hoque et al., 2004; Kabir & Howard, 2007; Mosler et al., 2010; Inauen et al., 2013; Hossain & Inauen, 2014), yet these studies have not explicitly considered users' own understandings of the various factors that are often assumed to shape social acceptability, as we do here.

In making this our focus, we also offer a working definition of the notion of social acceptability, building on and extending previous scholarship. First, in line with recent writings, we view social acceptability not as a static one-time decision but rather as a dynamic process (Shindler & Brunson, 2004; Escoffier & Grandclement, 2010). Furthermore, we define it here as "the willingness to receive and use" a given technology. We draw on existing literature (Davis, 1985; Hoque et al., 2004; Howard et al., 2006; Kabir & Howard, 2007; Madajewics et al., 2007; Shafiquzzaman et al., 2009) to identify a set of factors contributing to social acceptability. We then categorize such factors into two groups: first, attributes of the technological intervention itself; and second, user perceptions and water-related practices (see Figure 2.1).

Within the first category, we identify three factors: availability in sufficient quantities of the technology in question; its ease of use; and its affordability in terms of installation, operation, maintenance, and replacement costs. Within the second category, we include risk awareness about arsenic contamination, arsenicosis and risk versus benefits of using specific technologies; water quality beliefs (concerning, for example, taste, smell, temperature, arsenic free status, etc. of different water sources);and water use practices (such as relying on one source for multiple uses, as well as unlimited versus rationed use etc.).

2.3.2. User understandings of diverse factors shaping social acceptability

As we mentioned earlier, we relied on focus groups to investigate users' own understandings of various factors shaping social acceptability (Kuypers, 2009). It is important to note that in delineating such factors here, we do not see them as mutually exclusive or empirically distinct, but rather as (overlapping) analytical categories.

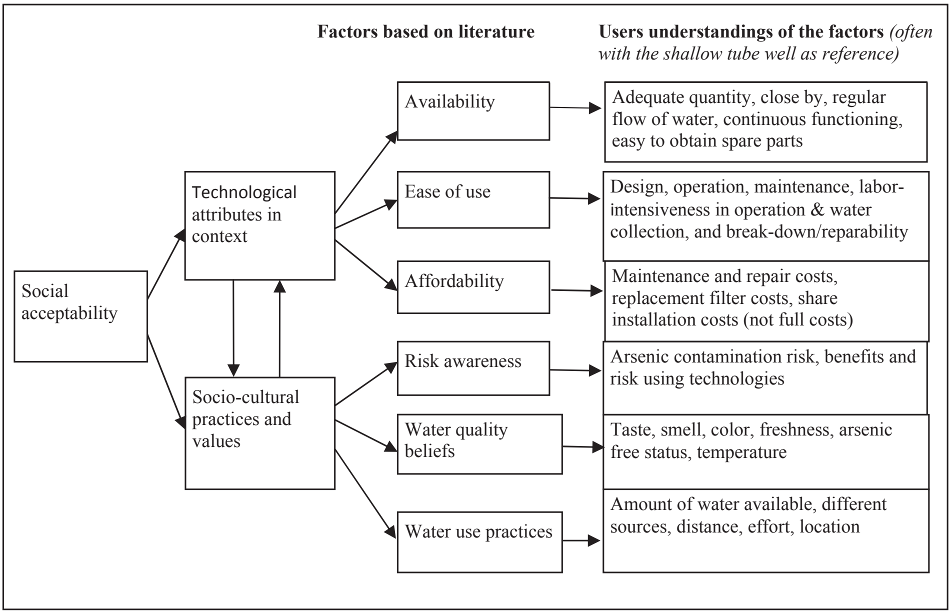

Figure 2.1: Factors shaping social acceptability

With regard to availability, all users received a technology only when the implementing agencies made it available to them. Hence, the factor "availability" as shaping social acceptability could potentially be rendered redundant as a result of this. Nonetheless, our findings suggested that understanding of availability varied somewhat across the three technology user groups. While all three user groups understood availability to mean an adequate number of technological units being available to meet safe water demand on a regular basis, Sono filter users also emphasized the regular and uninterrupted availability of the filter, which includes availability of spare-parts in local markets. Users of deep tube wells and improved dug wells, on the other hand, understood "availability" to also include an adequate number of units being available at convenient locations.

Ease of use as a factor shaping acceptability was understood in a similar manner by the three user groups to mean aspects relating to design, operation, labor-intensiveness, and maintenance. Such understandings of ease of use were shared across all technological user groups partially because the shallow hand pump tube well served as a shared comparative point of departure for all groups in their understandings of ease of use. User understandings of afford ability were also shaped by shared experiences across the three technology user groups. First, few users had a specific idea about the actual costs (market price) of the technologies they were using, as all were highly subsidized. Second, users considered it the responsibility of government (and NGOs) to provide them with technologies, regardless of costs. Nonetheless, when asked to imagine a situation without highly subsidized technologies, deep tube well and improved dug well users emphasized high upfront installation costs as an important element in their view on affordability, whereas Sono filter users also stressed the importance of costs related to filter and filter media replacement, in addition to first-time acquisition costs.

In articulating their understandings of how risk(relating to consuming arsenic contaminated water) influenced social acceptance of a given option, all users emphasized three key aspects: (i) the negative health consequences of consuming arsenic contaminated water; (ii) the (related) risks of not using arsenic safe technologies; and (iii) possible risks (but also benefits) of using specific arsenic safe technologies. These then shaped their assessment of the risks associated with drinking (or not) water from the alternative safe drinking water option that they had access to. Another key set of factors shaping acceptability related to user water quality beliefs, with users of different technologies emphasizing the importance of aspects such as (differing) taste, smell, color, freshness, arsenic free status and temperature of the water, in comparison with shallow hand pump tube well water as their frame of reference. Similarly, all users considered how their water use practices (had to) change with alternative, arsenic safe technologies, again with the shallow hand pump tube well as their reference point. Broadly, in considering this, users emphasized the importance of the overall amount of water available through a given option; as well as the challenge posed by the need to shift between multiple technologies in accessing water for different purposes (such as drinking versus washing or cooking). They also noted their views on how geographical aspects of (changed) water use practices (distance, effort, location of alternatives) shaped their acceptability of a specific option.

Diverse factors shaping social acceptability, according to the above delineated user understandings, are shown in Figure 2.1.

2.4. A User’s perspective on social acceptability: comparing different factors

Based on these user understandings of the factors determining social acceptability, this section analyzes which factors were seen by users themselves to be most important to shaping their own willingness to receive and use three arsenic safe drinking water options: the Sono Filter, deep tube well and improved dug well.

Figure 2.2 below depicts an overview of our findings, showing the percentage of each technology user group who viewed a given factor as important to shaping their acceptability of that specific arsenic safe option. We discuss in detail these findings below.

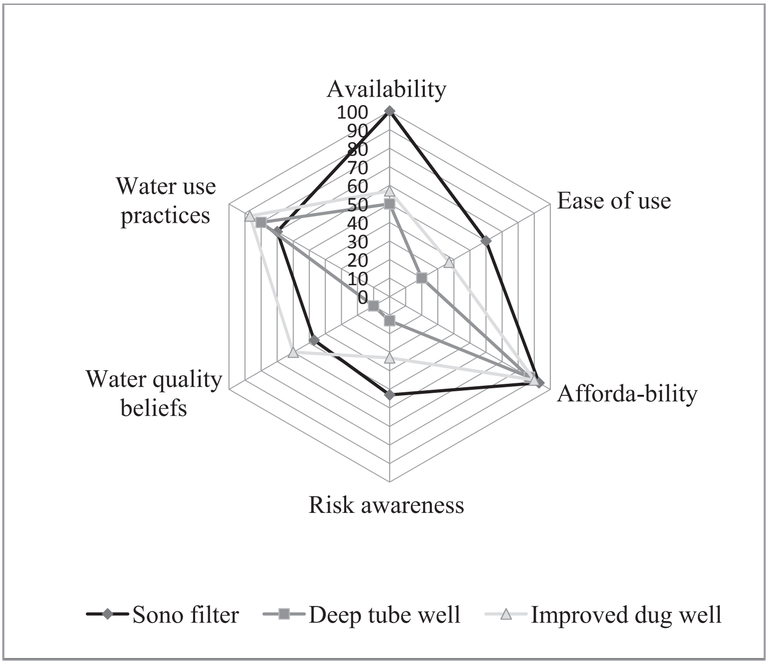

Figure 2.2: Percentage of users considering factors important in shaping their acceptability (as scored by the users; n=90)

2.4.1. Technological attributes in context: availability, ease of use and affordability

In this section, we outline our findings relating to how users viewed the technological attributes of the three examined technologies—Sono filter, deep tube well and improved dug well—in determining social acceptability, i.e. their willingness to receive and use each option. We discuss below users' views on three factors: availability, ease of use, and affordability.

Availability of arsenic safe technologies

In securing social acceptability of given technologies from a user perspective, , the factor "availability", as understood by users, proved important for all Sono filter users, but only for half of the deep tube well (50%) and improved dug well users (56.67%) (Figure 2.2). This was especially because new Sono filters and spare-parts were not available in the local markets, and could only be provided by the implementing agency during the project period. In addition, 40% of the Sono filter users experienced a break-down of their filter within one year after use. In practice, very few filters served a life span of five years, due to poor maintenance. One Sono filter user interviewee (December 10, 2011) noted that, "a few years ago, an NGO provided us a filter that we used until it was broken after one year. Spare-parts are not available in the local market and we have no other option, but depending on the NGO for getting such filter".

Consequently, the same household continued to use contaminated shallow tube well ground water, as no new filter became available from the implementing agency. Therefore, dependency on the NGO for receiving the filter and non-availability of spare-parts significantly lowered social acceptability of this technology, in the eyes of its users.

In the same way, availability of both the deep tube well and the improved dug well was entirely dependent on the projects. Female users revealed that both these technologies had high longevity, if maintained properly. But availability of an adequate number of units to serve demand in the villages was of major concern. As one deep tube well user noted (interview January 4, 2012), "we need more deep tube wells, as our village*,* where 3,000 people live, has only four deep tube wells, which is inadequate."Nonetheless, the availability of spare-parts in local markets and assurance of getting new deep tube wells through government projects contributed to securing greater acceptability of this technology. In contrast, in the case of the dug well, the lack of spare-parts in the local markets (except for the hand pump) and no assurance of getting new improved dug wells from the NGO in coming years constrained the acceptability of improved dug well. Furthermore, the selection of locations for installing community-level technologies (both deep tube well and improved dug well) proved crucial for ensuring social acceptability of these technologies among users. Half the users of both the deep tube well and improved dug well were concerned with the aspect of location, as socio-religious norms do not allow adult and young women to source water from a distant community spot. Therefore, availability of an adequate number of deep tube wells and improved dug wells at short-distance locations was seen as vital to securing social acceptability of these technologies.

Hence, the lack of availability of the Sono filter (and filter media) after the project period ended lower edits social acceptability, whereas the (potentially) inadequate number of deep tube wells and improved dug wells at suitable locations close by lowered to some extent social acceptability of these technologies. The long lifespan and government's assurance of supplying more deep tube wells in coming years enhanced social acceptability of this specific option.

Ease of use

In the case of the household-level Sono filter, technological design, operation and maintenance (and related labor intensiveness) and vulnerability to breakdown were central concerns to the users in assessing ease of use. Around 60% of the Sono filter users considered ease of use to be important to securing acceptability (Figure 2.2). Among these users, two-thirds faced periodic break-down of the Sono filter. Subsequently, the iron filter stand had been converted often into a cloth-drying rack, whereas the plastic buckets turned into storage pots for preserving rice and vegetables. As noted in an interview with a female Sono filter user (December 12, 2011), the poor plastic quality made the bucket of the Sono filter system fragile and prone to damage, hindering its long-term usability. In general, many female users noted that the maintenance and cleaning of filter media and of the two buckets was troublesome and labor intensive.

Furthermore, users were concerned with slow filtration rates and clogging, which made them reluctant to use the filters regularly.

On the contrary, 80% of the deep tube well users did not experience major problems in using the technology, which contributed to enhanced social acceptability. This could be because the users already had adopted operation and maintenance routines of tube well technology. Male users of deep tube wells were better able to repair small, regular occurring, technical problems, which was not the case with the household filter and the improved dug well. However, 20% of deep tube well users noted that pressing the handle was laborious for female users, in particular during the summer, requiring due consideration in securing long-term use and acceptability. The collection of water from community wells was also found laborious for female users living at greater distances. About one-third of the improved dug well users found ease of use crucial in ensuring social acceptability (Figure 2.2). A few of these users highlighted the problem of potential microbial contamination of the wells, making regular cleaning (for example, chlorination through using bleaching powder) essential. During the dry season (March-August), groundwater levels are usually lower and users cannot get sufficient amount of water, particularly from improved dug wells. Furthermore, in the monsoon season, improved dug wells in low-lying areas, like Manikganj, were vulnerable to flooding. Hence, seasonal malfunctioning of improved dug wells and their troublesome cleaning hindered its social acceptability. In sum, compared to Sono filter and improved dug well, deep tube well was less affected by problems associated with ease of use in securing social acceptability.

Affordability

After the detection of arsenic in groundwater, the users who had recently installed a shallow hand pump tube well for US$ 100-130 were now required to spend money once again on arsenic safe technologies. In general, all three arsenic safe technologies are costly for users, and hence installation of these three technologies was perceived to be impossible without the support of implementing agencies. As a result, all three arsenic safe options were strongly supply-driven and project-dependent.

This notwithstanding, our findings showed that users considered affordability a crucial factor in ensuring social acceptability of the technologies (93% of Sono filter, 87 percent of deep tube well, and 90% of improved dug well; Figure 2.2). In theory, for Sono filters, users had to pay a small share (US$ 4.5) of the filter cost, yet in practice they only paid for transportation costs. On the other hand, a group of 10 households was required to spend US$ 58-65 collectively as a community contribution to receiving a deep tube well or an improved dug well. The community-level technologies (deep tube well and improved dug well) were mostly installed in the courtyards of influential and solvent families, as these families covered the total community contribution on behalf of the user groups, and sponsored the location for installing the technology. Hence, the majority of users did not financially contribute to installing the arsenic safe technology. Although the installation cost was relatively high for community-level technologies, the actual cost of Sono filter was much higher, considering its short life time (five years in theory, much less in practice according to focus group participants), service coverage and required replacement cost of filter media once every two years. In contrast, despite having a high installation cost, the long life time (more than 20 years) of deep tube well (and improved dug well, if not malfunctioning) made these technologies cost effective, compared to the Sono filter.

In three cases, users did not want to spend US$25 to repair a community-level improved dug well, as mentioned by host households (who were caretakers of the technology). Similarly, all Sono filter users did not want to spend money for replacement of filter media, let alone for buying a new filter. Hence, affordability is clearly a driving concern in determining social acceptability of the Sono filter. According to the participants of focus group sessions and the individual interviewees, no new households showed willingness to pay for an improved dug well in the post-project period, when households had to cover the full installation costs. Many villagers showed interest to install a deep tube well at community-level, if the installation costs were somewhat reduced or subsidized. The implementing agencies (DPHE and NGOs) that cannot cover (part of) the installation costs face difficulties in securing social acceptability of these technologies, as they are not affordable in poor rural areas.

2.4.2 User beliefs and practices: risk awareness, water quality beliefs and water use practices

In this section, we outline our findings on how user understandings of arsenic risks, their beliefs about water quality, as well as their water use practices at individual and community level shaped their acceptability of the three examined technologies—Sono filter, deep tube well and improved dug well.

Risk awareness

Our research revealed that varying levels of user awareness of risks associated with drinking arsenic contaminated water, and the health benefits of using arsenic safe technologies, did influence acceptability of the specific technological options (various interviews). As Figure 2.2 shows, about half of the Sono filter users (53%) linked their awareness of risk to greater acceptability on their part of the technology in question, while such a link was significantly lower for deep tube well (13 percent%) and improved dug well users (33%). The high risk awareness amongst Sono filter users is explainable by the fact that female Sono filter users (20, but no male ones) received training on how to use the technology, compared to no females, and only five and six male users, of deep tube well and improved dug well respectively (i.e. those who were caretakers of the technology). Another reason for the elevated risk awareness among Sono filter users was the presence of a large number of arsenicosis patients (594) in adjacent villages. Despite this difference in risk awareness across technology user groups, all users did have basic knowledge about the negative consequences of consuming arsenic contaminated water, but not all had detailed and specific knowledge. For instance, more than half of all arsenic safe technology users believed that arsenicosis is a contagious disease (focus group sessions) suggesting that risk-related information was not always interpreted as intended.

Female Sono filter users were better informed about the potential (health) benefits of using arsenic safe technologies, as compared to female users of the deep tube well and improved dug well. However, male Sono filter users were found to be reluctant to acknowledge the benefits of these arsenic safe technologies. As one participant in a focus group session (December 14, 2011) noted, “my mother [has been] an arsenicosis patient for three years but I am not, although both of us drank water from the same contaminated source. Then why should I use the filter?” A challenge in linking risk awareness to greater social acceptability for all three technologies is that the clinical manifestation of arsenicosis takes up to 10-15 years. Such long latency periods do no aid in increasing awareness of risk and a concurrent desire to avoid risk by using arsenic safe technologies. As a result, forty percent of Sono filter users, whose filters were abandoned, started relying on contaminated tube wells again, instead of replacing the old filter, despite their overall higher levels of risk awareness. Similarly, one-third of the improved dug well users continued to rely on contaminated shallow hand pump tube well water, when the dug well technology was periodically dysfunctional. Deep tube well users had fewer instances of such dilemmas, since the technology was functional for a longer term, and year round.

With regard to risk perceptions relating to use of the alternative technology itself, deep tube well users considered this particular technology to be very safe. Sono filter users, and improved dug well users, were only to a minor extent concerned about possible risks related to use of these specific technologies. For instance, although Sono filter users were instructed to put the filter sludge in a pot to avoid adverse health effects from exposure, no one was found to be concerned about this aspect. In addition, no Sono filter user knew how long the filter media would continue to remove arsenic from contaminated water. Similarly, users of improved dug well did not express concern about potential microbial contamination. Furthermore, neither user group considered testing the water in order to detect the presence of arsenic and other (microbial) contaminants therein. These findings suggest, paradoxically, that instead of higher risk awareness resulting in higher social acceptance of arsenic safe options, in certain instances, lower awareness and/or concern with the risks associated with these technologies led to higher social acceptance, since users ignored such risks. This is an important dynamic to keep in mind in assessing the linkages between levels of awareness about potential risks and benefits associated with use of specific technologies, and their social acceptance.

Water quality beliefs

Although arsenic contamination does not induce any change in color, smell and taste of water, users often considered arsenic—and even arsenic safe technologies—as being responsible for causing such changes. Improved dug well users exhibited the strongest link between (their perceptions of) water quality, and their acceptance of the relevant arsenic safe technology. These users noted problems with the taste, color and smell of dug well water, and their perception that it was not fresh, because it was stored in the protected dug. Sono filter users also perceived a lack of freshness in filtered water. In contrast, the deep tube well was perceived by users as providing fresh and tasty water. A dominant additional belief among Sono filter users was that using filtered water could cause cold in the chest during winter. This discouraged users, especially elderly people and children, from drinking filtered water, and/or reduced the amount of water intake, despite efforts of implementing agencies to convince users that this was not the case.

In addition, water quality beliefs centered around arsenic itself were also linked to varying social acceptability of arsenic safe technologies, as focus group sessions showed. Thus, some Sono filter and improved dug well users believed that these two technologies did not adequately remove arsenic from the ground water and/ or could not deliver arsenic safe water, because no chemicals were used. Widespread information provided by governmental agencies and NGOs in earlier decades was that water from dug wells was not pure and required decontamination; which hindered its acceptability, despite the fact that the technology had since been upgraded. Furthermore, some users of all three technologies considered arsenic contamination to be a curse of God, and hence were not prepared to take action themselves in avoiding the contamination; although they did accept to use given arsenic safe technologies. Deep tube well users, on the other hand, did not articulate such water quality related beliefs that discouraged them from accepting and using the technology.

In sum, user beliefs about water quality had considerable influence on the social acceptability of various arsenic safe technologies. As Figure 2.2 shows, more than half of the improved dug well users (60%) as well as almost half of the Sono filter users (47%) considered these beliefs to be of major importance for the social acceptability of these two technologies, which was much less the case among deep tube well users (10%).

Water use practices

Local water use practices in the study areas were all shaped by longstanding use of the shallow hand pump tube well prior to the arsenic contamination crisis, , which enabled users to get an unlimited quantity of water from their own backyards, and in quantities sufficient to serve multiple purposes (drinking, cooking, cleaning, bathing). These water use practices had to change with the introduction of arsenic safe technologies, since the unlimited access to drinking water provided by the shallow hand pump tube well to each rural household was no longer available. In one focus group session with Sono filter users (December 12, 2011), one participant noted that “since we are informed about contamination, we lost our traditional control and access over unlimited amounts of drinking water. In addition, we need to rely on other sources of water, such as ponds and canals, along with contaminated shallow hand pump tube wells, for cooking, bathing and household activities.”

Most Sono filter users thus did not use filtered water for cooking, although one third of them occasionally used filtered water for cooking rice, as they believed the water enhanced the taste of rice. In addition, two-thirds of Sono filter users argued that these filters were unable to fulfill households' demand for drinking water, as it took too long for the water to move through the filter. Thus, use of the Sono filter required two changes to the traditional water use practices: first, relying on different water sources and technologies for different purposes; and second, limitations on the quantity of available safe drinking water.

Deep tube well and improved dug well users highlighted the importance of such changes as well, and also noted added significance of changed water collection practices. Collecting drinking water from a distant source, such as a community-level deep tube well and improved dug well, is often considered time-consuming and labor-intensive, putting additional burden on females. We found that female users from distant households that had to continue to rely on contaminated shallow hand pump tube wells for purposes other than drinking and cooking. Overall, a high percentage of users across all three technological options (70% of Sono filter, 80% of deep tube well and 87% of improved dug well users) stated that the required changes in water use practices are significant in shaping social acceptability (Figure 2.2).

2.4.3. Comparative acceptability to users of the three arsenic safe options

Following on from focus group discussions about the relative importance accorded by users to the different factors shaping social acceptability, we concluded our empirical data generation by asking all 90 participants in the focus groups to (individually) qualitatively assess their overall level of acceptability of the technology in question, across three scales (highly acceptable, moderately acceptable, and minimally acceptable) (Table 2.2).

Table 2.2: Overall acceptability to users of three arsenic safe technologies (N=90)

Technologies	**Highly acceptable** **N (%)**	**Moderately acceptable** **N (%)**	**Marginally acceptable** **N (%)**	**Total** **N**
Sono filter	4 (13)	15 (50)	11 (37)	30
Deep tube well	23 (77)	4 (13)	3 (10)	30
Improved dug well	3 (10)	13 (43)	14 (47)	30

As Table 2.2 reveals, despite the problems associated with availability at an appropriate location, affordability (cost sharing), and changes in water use practices (including additional time and labor spent to collect water), the technological option of the deep tube well is seen as a highly acceptable technology by three-quarters (77%) of its users. This finding was also reinforced by the data generated in the focus group sessions and individual interviewees. In contrast, half of the Sono filter users graded this arsenic safe option as moderately acceptable, whereas one-third considered it to be only marginally acceptable. Similarly, 47% of the improved dug well users considered this technology to be marginally acceptable, whereas 43% viewed it as moderately acceptable. Very few Sono filter users (13%) and improved dug well users (10%) assessed their technology to be highly acceptable. Concerns with availability, affordability, perceived water quality and changed water use practices were the main reasons (as documented earlier in Figure 2.2). Focus group discussions and interviews revealed, in addition, that very few rural people who were exposed to the risk of arsenic contamination wanted to receive and use the improved dug well technology. Focus groups with Sono filter users also indicated that households did want to receive Sono filter technology, but only if filters were highly subsidized, as it would take away a major (financial) worry, and would enable female users to manage safe drinking water within their households, and thus conform with social norms.

2.5. Discussion and conclusion

Since the social acceptability of arsenic safe technologies is key to their successful dissemination in rural Bangladesh, this paper assessed users' own perspectives on social acceptability of three technologies: the Sono filter, deep tube well and improved dug well. In doing so, we had a two-fold aim. First, we assessed how users themselves understood a diverse array of factors influencing their acceptance (or not) of these technologies. Second, we drew on these user understandings of key factors shaping social acceptability to estimate the relative acceptability of each technology to its users in our areas of study. Most studies in this field (e.g., Hoque et al., 2004; Howard et al., 2006; Mosler et al., 2010; Inauen et al., 2013) draw on expert conceptualizations of social acceptability in assessing whether arsenic safe options are likely to secure social acceptance, even those that study users' views. Our investigation has focused, instead, on how technology users themselves understand the factors that constitute social acceptability.

With regard to such user understandings, our findings reveal that, although all three arsenic safe technologies we examined were highly subsidized and made available through projects, user views varied with regard to availability and affordability of the technologies, as key factors shaping their social acceptance of them. Despite the subsidized provision of the technology, Sono filter users highlighted its short life span, recurrent costs (relating to installation, operation, maintenance, and filter replacement), and lack of an uninterrupted supply of filters as crucial factors inhibiting their acceptability of it in the long run. Deep tube well and improved dug well users, however, saw these technologies as being more affordable and available, notwithstanding higher initial installation costs and potentially inconvenient locations of such technologies.

Our analysis revealed, furthermore, that additional factors assumed to shape social acceptability of a given technology, such as ease of use, risk awareness, water quality beliefs, and water use practices, were all understood in a similar manner by users across all three technologies. This is explainable by the fact that user understandings of these factors were strongly influenced by their collective prior experiences with the shallow hand pump tube well as a reference technology.

With regard to the second aim of our analysis, to draw on user understandings to assess the relative importance of different factors in shaping social acceptance of the studied technologies, our analysis shows that not all factors were seen by users as equally important. In general, availability, affordability and water use practices were seen as the most crucial in securing acceptance of all three arsenic safe technologies. This finding again diverges somewhat from earlier studies that have focused most attention on ease of use (operation and maintenance) and user perceptions of water quality beliefs (taste, smell and color).

In particular, availability of alternatives has not been considered an influential factor shaping social acceptability in earlier studies. One reason is that since arsenic safe options were being made available by project developers or the government to users, the starting assumption of earlier social acceptability studies has tended to be that an option is already available to the users. Our study is important in documenting, however, that user understandings of availability vary (for instance, including not only one-time access but also an assurance of getting a technology in an uninterrupted and timely manner), and that such varied understandings play important roles in shaping acceptability of a specific arsenic safe option.

With regard to affordability, our analysis reveals that the deep tube well is regarded by users as a cost-effective technology, compared to the other two arsenic safe options, a finding that is consistent with other research (Hossain & Inauen, 2014). Other analyses (for e.g., Mosler et al., 2010; Inauen et al., 2013; Hossain & Inauen, 2014) have also highlighted that perceived (lack of) affordability is a challenge in securing social acceptability of arsenic safe technologies. Our analysis is aligned with such previous work, in highlighting that poor users cannot afford the (limited) cost sharing involved in their dissemination and use, despite heavy subsidization of the technologies in question. We also show, furthermore, how users' perspectives on affordability and availability are linked. For example, where wealthier families pay the full cost of cost-sharing arrangements between providers and users for the deep tube well and improved dug well, this has resulted in the technologies being placed at a location desirable and suitable for them, thus potentially lowering accessibility of these technologies for poor users. While some studies have noted the contribution of wealthier people in cost sharing, making such options more affordable for others(e.g., Inauen et al., 2013), they have not always noted linkages with other factors shaping social acceptability, in this case between availability and affordability.

With regard to changing water use practices, this has been examined in other studies only in terms of distance to water source and water collection times (e.g., Hoque et al., 2004; Shafiquzzaman et al., 2009; Mosler et al., 2010), rather than also assessing aspects such as limited versus unlimited quantities of water available; and issues relating to one versus multiple source of water to serve multiple needs.

The remaining factors assessed in our analysis, including ease of use, risk awareness, and water quality beliefs, have had, our findings show, a greater impact on(low) user acceptability of the Sono filter and improved dug well (as compared to the deep tube well), a finding that is in line with earlier studies (Alam & Rahman, 2011; Inauen et al., 2013; Hossain & Inauen, 2014). This is because users do not differentiate between deep tube well and shallow hand pump tube well (their reference technology) in terms of ease of use, risk awareness, and water quality.

Finally, in distilling a comparative overview of the level of social acceptance of each of these arsenic safe technologies from the users' perspectives, our analysis shows that the deep tube well is graded as highly acceptable by most of its users, consistent with some previous studies (Paul, 2004; Mosler et al., 2010; Inauen et al., 2013; Hossain & Inauen, 2014). Improved dug well and Sono filter are seen as less acceptable by most users. This is in contrast to some other studies (for e.g., Shafiquzzaman et al., 2009; Inauen et al., 2013), which have claimed that the Sono filter was a highly preferred option, along with deep tube well, by most users. Our findings do replicate the conclusion of Inauen et al. (2013) and Hossain & Inauen (2014) that improved dug well technology is the least preferred option. Compared to other arsenic safe technologies, especially users' risk awareness (microbial contamination), and water quality beliefs (smell, taste and color) hinder the acceptability of the improved dug well.

We conclude, then, that also from a technology user's perspective, the installation of an adequate number of deep tube wells at convenient locations is likely to be the most socially acceptable arsenic safe option of those currently disseminated in rural Bangladesh. With regard to the Sono filter, despite problems associated with availability, ease of use, affordability and water use practices, our findings highlight that such filters could gain greater social acceptability in those regions where the deep tube well is not feasible (e.g. for geo-hydrological reasons), provided such aspects are addressed. Improved dug well is the least viable arsenic safe technology, given its low social acceptability.

In concluding, our analysis suggests that instead of relying on expert conceptualizations of social acceptability alone, user understandings of what constitutes social acceptability provide an important avenue through which to grasp why certain technologies are judged to be more acceptable than others. As such, this paper has advanced a "user's framework" on social acceptability, one that provides new insights into how users themselves view the importance of factors such as availability, affordability and compatibility with existing water use practices in shaping social acceptability. It has also documented how other factors, such as ease of use, risk awareness, and water quality beliefs, shape the varying social acceptability of specific arsenic safe options. Our analysis also suggests, moreover, that as a dynamic rather than a static process, securing greater social acceptability of any specific option can become feasible, if implementing agencies and policy actors focus on user views on existing hurdles to acceptance.

The analysis in this paper can be usefully augmented by future research on the interrelatedness of the factors studied here in determining social acceptability, as well as the differences in understandings of social acceptability between users and non-users in the same geographical location. It could also be useful to compare divergent understandings of social acceptability between users and other key actors (such as local government or technology providers). Finally, comparison with arsenic safe alternatives not analyzed here, including well switching, or piped water supply systems as two promising alternatives would be important.

Appendix 1: Photos of the three technologies (deep tube well, improved dug well and Sono filter)

Chapter 3

The consolidation of deep tube well technology in safe drinking water provision: the case of arsenic mitigation in rural Bangladesh

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Abstract

This paper explains why and how deep tube well as a safe drinking water technology has become dominant in mitigating the arsenic crisis in rural Bangladesh. We do so by applying insights from the Multi-Level Perspective on transitions in explaining changes to the socio-technical safe drinking water regime in rural Bangladesh. Data about seven dimensions of regime change was gathered from key actors, through in-depth interviews, focus groups sessions, a survey and a workshop. The findings reveal that with the introduction of deep tube well as an arsenic mitigation technology, the observed changes in the seven dimensions help to transform the existing safe drinking water regime in order to re-stabilize it. Technological attributes, symbolic meaning, industry structures, and techno-scientific knowledge have supported an evolving dominance of the deep tube well. Besides, user practices as well as related infrastructures have adapted to the use of deep tube wells, and new policies stimulated its application. We argue that the dimensions of the technology change in the existing regime are consistent with the features of incremental innovation. By offering such insights, we show the relevance of the Multi-Level Perspective on transitions to analyze socio-technical innovation in a developing world context.

3.1. Introduction

Massive arsenic contamination in shallow hand pump tube wells–the main drinking water source in rural Bangladesh– severely limits rural people's access to safe drinking water (Ahmed, 2002; Atkins et al., 2007; Nahar, 2009; Chakraborti et al., 2010; Milton et al., 2012). An estimated 52 million people are exposed to arsenic by consuming arsenic contaminated drinking water beyond the Bangladeshi safety limit of 50 µg/L (Milton et al., 2006; DPHE & JICA, 2009). With the aim of providing safe drinking water to rural populations, the government of Bangladesh has introduced several technological innovations in recent years, in partnership with donors and NGOs. These technological innovations fall into two categories, first, filter and treatment technologies designed to remove arsenic from contaminated shallow tube well water, such as household and community-level filter systems; and, second, alternative safe water options that do not require treatment of arsenic contaminated water. These include piped water supplies, deep tube wells, improved dug wells, designated safe shallow hand pump tube wells, and rain water harvesting (Hoque et al., 2004; Ahmad et al., 2006; Inauen et al., 2013; Kundu et al., 2016a).

After its initial introduction into areas where the water table was low, the deep tube well technology now dominates 84.4% of the total mitigation effort (DPHE & JICA, 2009). Many studies (Hoque et al., 2004; Kabir & Howard, 2007; Shafiquzzaman et al., 2009; Johnston et al., 2010; Inauen et al., 2013; Hossain & Inauen, 2014) have confirmed that the deep tube well is a widely preferred technology in rural Bangladesh, with an emphasis on its social acceptability and technical performance. There is still a need, however, to analyse the dominance of the deep tube well within the broader context of technological innovation and diffusion stimulated by the onset of the arsenic crisis. In particular, we deploy here the Multi-Level Perspective on transitions (Geels, 2002) to examine seven dimensions of the existing safe drinking water socio-technical regime in place in Bangladesh, changes within which help to explain, we argue, the evolving dominance of deep tube well technology as a safe drinking water option. These seven dimensions include: i) technological attributes of a given mitigation option; ii) user practices and application domain (i.e. the market); iii) symbolic meaning attached to the technological option; iv) the infrastructures necessary for its dissemination; v) industry structure (i.e. production practices and options); vi) policy; and vii) techno-scientific knowledge necessary to develop, disseminate and use a given technology.

In seeking to understand the dominance of deep tube well technology through analysing adjustments within these seven dimensions, we explain here the dynamics of the safe drinking water regime in the context of arsenic mitigation, including its resilience but also its propensity for change. In doing so, this paper explains the change mechanisms and magnitude of change in the seven regime dimensions, and thereby illustrates how and why the deep tube well has become dominant as a safe drinking water option. We conclude by briefly considering why novel or radical technological innovations might have limited capacity to re-stabilize an existing safe drinking water regime, and why incremental innovations, such as the deep tube well, remain an important element of socio-technical regime stabilization. The multi-level perspective on transitions is extensively used in the developed world to explain socio-technical change (see, for example, van Vliet et al., 2011, for an analysis of utility infrastructures). However, its application in the developing world (and specifically in the rural context of Bangladesh, with regard to safe drinking water provision) is yet to be explored. This makes our analysis an important test case for assessing the utility of this conceptual lens within a rural developing country context.

We proceed as follows: the next section presents our conceptual approach based on the Multi-Level Perspective (henceforth MLP). Section 3.3 presents our research methods, study area and research approach. In Section 3.4, we present our findings and Section 3.5 contains a discussion and conclusions.

3.2. MLP on transitions: stability and change in socio-technical regimes

To analyse the emergence and consolidation of a single technology in society, we could rely on a number of analytical frameworks. The classical "Diffusion of Innovations" by Rogers (1962) would be one approach to analysing uptake of new technologies by groups in society. Alternatively, the Technological Innovation System (Markard et al, 2012; Twomey & Gaziulusoy, 2014) is concerned with understanding the diffusion of particular technologies and their systemic embedding in broader structural contexts. For the purpose of our research, we select the MLP framework because we can deploy it to explain the dominance (or not) of a particular technological innovation within the dynamics of a broader transition process in society. MLP is part of transition theory, and has been developed to explain socio-technological changes in a particular domain. According to MLP, new technologies become dominant through a transition process (Geels & Kemp, 2007). Transitions come about through interactions at three analytical levels: niche, socio-technical regime and socio-technical landscape (Geels, 2002; Schot, 1998; Oyake-Ombis et al., 2015). A niche is conceptualized as a protected space wherein radical innovations emerge, are tested and learned from. The socio-technical regime is conceptualized as"... relatively stable configurations of institutions, techniques and artefacts, as well as rules, practices and networks that regulate the innovation" which includes the interaction between scientists, users, policy makers, societal groups besides engineers and firms (Rip & Kemp, 1998: 340). Lastly, the broader landscape refers to contextual dimensions such as economic growth and environmental problems (for instance, arsenic contamination) (Geels & Kemp, 2007). Such landscape factors can partially destabilize an existing socio-technical regime, thereby creating opportunity for radical or niche innovations (e.g., arsenic removal technologies) to emerge (Schot & Geels, 2008).

Based on the above understanding of MLP, we explore stability and change within seven dimensions of an existing sociotechnical regime, in seeking to explain the dominance of deep tube well as a safe drinking water option. These dimensions include: technological attributes; user practices and application domains; symbolic meanings of technology; infrastructures; industry structure; policy; and knowledge (Schot, 1998; Geels, 2002). Our focus here, furthermore, is on exploring change mechanisms and the magnitude of change occurring in each of these seven dimensions. According to MLP, change can occur through three distinct mechanisms: reproduction, transformation and transition (Geels & Kemp, 2007; Geels & Schot, 2007). *Reproduction* of existing technological configurations occurs through incremental changes brought about by regime actors, during periods when the regime is stable. *Transformation* comes about through interaction between the regime and landscape level (with only minor influence from niches), where outsiders and incumbent regime actors respond to changing landscape influences through reorientation and adaptation of an existing sociotechnical regime. Lastly, a *transition* occurs when regime actors fail to solve regime problems, and novel innovations developed and nurtured in niches gain a breakthrough into the regime.

With regard to change mechanisms, there is no *a priori* expectation about which one takes precedence over another. Furthermore, assessment of change mechanisms can only occur in specific contexts. In assessing the conditions under which a given change mechanism comes to the fore in our case, we proceed as follows: we first analyse the nature and extent of the changes, if any, to the seven dimensions of the safe drinking water socio-technical regime, resulting from introduction of the deep tube well. We then assess the overarching change mechanism this represents for the safe drinking water regime in rural Bangladesh. In other words, by studying the magnitude of change taking place in the seven dimensions of a regime, we can assess how and why (i.e. through what change mechanisms) the deep tube well has become dominant in the context of arsenic mitigation (See Figure 3.1). Our overarching aim is to shed light on the pathways of stabilization and/or change (reproductive, transformative or transition) that can help explain the consolidation and dominance of deep well technology in the safe drinking water regime in the context of arsenic mitigation in rural Bangladesh.

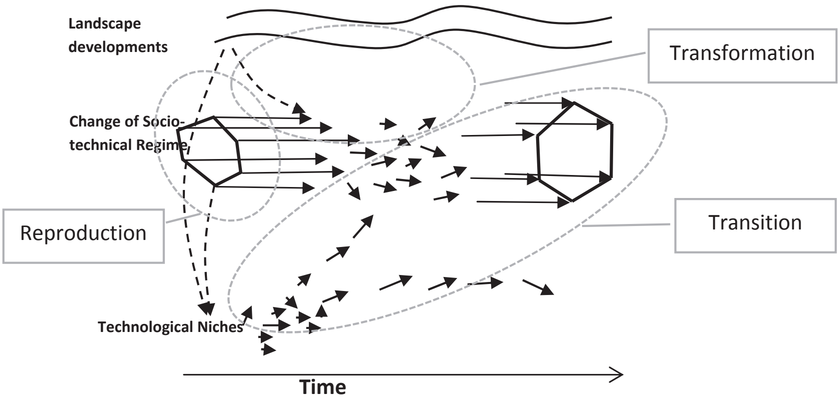

Figure 3.1: Multi-Level pathways of change in a socio-technical regime. Source: Rip & Kemp (1998); Geels & Kemp (2007)

3.3. Methods

To understand the dominance of deep tube well technology in the safe drinking water socio-technical regime in the context of arsenic mitigation, a case study methodology was followed, with use of qualitative and quantitative data collection methods. Qualitative data about the safe drinking water socio-technical regime was collected from regime actors, using in-depth interviews, focus group sessions, and workshop (see Table 3.1). The purpose of in-depth interviews and focus group sessions was to gather data on the seven dimensions of the socio-technical regime. The purpose of the workshop was to generate information on the allocation, installation, infrastructure and availability of deep tube well technology in the context of, but also beyond, arsenic mitigation in rural Bangladesh. A semi-structured questionnaire was also distributed and was designed to gather quantitative data from deep tube well users on technological attributes, user practices and techno-scientific knowledge.

To understand the dominance of the deep tube well as a mitigation option, data was collected from two levels. Firstly at local-level, we selected *Uttar Suchipara* Union (lowest administrative unit of local government), situated in Chandpur, an East-central district of Bangladesh, 115 kilometres away from the capital, Dhaka (See Appendix 1 for study area). This area was selected for two reasons: i) 98.4% of the tested shallow hand pump tube wells in this Union were severely contaminated by arsenic (DPHE office archives, 2013); and ii) the relatively wide availability here of deep tube well technology. Secondly, national-level data on policies, industry structure and dissemination was collected from multiple sources, including national policy makers and organizations in Dhaka.

Table 3.1: Techniques of data collection and respondents

Techniques	Respondents (number)
In-depth interviews	3policy makers from Policy Support Unit 3 donors: 1 each from UNICEF, JICA and WHO 10 implementing agencies: 6 with DPHE, 2 with BRAC, 1 with NGO Forum for Public Health 6 engineers from DPHE 9 community representatives 6 scientists and experts: 1each from BCSIR, BUET, DU and 3 independent experts 4 hardware shops 3 foundry industries 3mesons
Focus group sessions	2 female and 2 male users
Survey questionnaire	99 households
Workshop on prospects and challenges of disseminating arsenic mitigation technologies in Uttar Suchipara Union	15 participants including Upazila chair, Union Parishad chair and members, community leaders, DPHE engineer, BRAC executive and users

We conducted 47 in-depth interviews with regime actors related to innovation and dissemination of deep tube well (See Table 3.1). In addition, four focus group sessions, including two with only male or only female users, were organized. Furthermore, one workshop was organised, where 15 regime actors participated, including DPHE, Upazila Parishad, Union Parishad, government officials, NGOs, community representatives and users.

Before selecting survey respondents, we collected comprehensive lists of households that were currently using deep tube well, from the DPHE and Union Parishad offices. The number of households using a deep tube well in the union totalled 880, of which 99 households (>10%) were randomly selected to participate in our survey. A cross-sectional survey was carried out among the users (50% female) of the deep tube well from November 2011 to January 2012. We also simultaneously collected data from numerous secondary sources, including academic articles, office achieves and scientific and policy reports, in order to analyse the historical and policy context for dissemination of deep tube well technology.

3.4. The safe drinking water regime for arsenic mitigation: growing dominance of deep tube well technology

In the 1970s, the government of Bangladesh, along with financial and technical support from UNICEF and some NGOs, triggered a major shift from surface water to ground water sources. This was done primarily through installing the shallow hand pump tube well, acknowledged to be a cheap and relatively simple safe drinking water option (Black, 1990). Although there is lack of systematic data, estimations confirm that about 10 million shallow hand pump tube wells were installed in the last four decades, of which 75% were privately owned. This shallow hand pump tube wells installation program ensured safe drinking water to the 97% of rural people– a remarkable public health success (WSP, 2000; Ahmed, 2002). With the steady involvement of the private sector in this process, including manufacturers, retailers and media, this single technological innovation succeeded in establishing the safe drinking water socio-technical regime in rural Bangladesh.

In 1993, after the detection of naturally occurring arsenic in the ground water in Bangladesh, this safe drinking water regime became partially destabilized. An estimated 29% of the total shallow hand pump tube wells installed were claimed to be contaminated by arsenic (the actual number was yet to be confirmed as not all wells were tested)(Ahmed, 2002). As part of arsenic mitigation, deep tube well technology was introduced, along with a number of other technologies, in the late 2000s. Deployment of deep tube well technology was not entirely new, as it was installed previously in the coastal belt and in the areas where the water table was low, i.e. those areas where the shallow tube well was less feasible.

An estimated 165,000 deep tube wells were installed between 2000 and 2005 throughout the country, mostly by the Department of Public Health Engineering (Ahmed et al., 2006; Escamilla et al., 2011). Within a few years, the number had increased to 195,603 (DPHE Planning circle,

2007) (DPHE & JICA, 2009). Figure 3.2 presents a consistent trend of recent national-level dissemination of 70,648 deep tube wells from 2006 to 2011. Besides, several NGOs installed deep tube wells through various arsenic mitigation projects. According to a compilation by Ravenscroft et al., 2009, deep tube well technology has become dominant (84.4%) among the arsenic mitigation technologies followed by safe shallow hand pump tube wells (5.1%) and improved dug wells (4.9%), rainwater harvesting (3.2%) and pond sand filters (1.4%) (See Figure 3.3).

We turn next to exploring changes that have (or have not) taken place in the seven dimensions of the safe drinking water socio-technical regime, in order to explain such dominance of the deep tube well option.

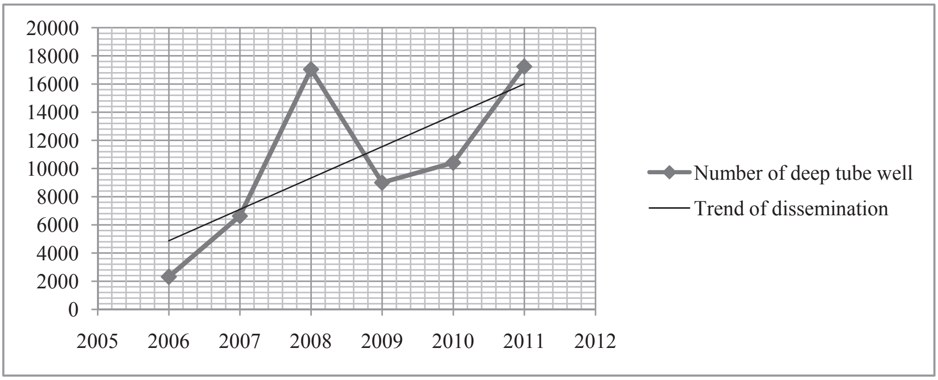

Figure 3.2: Year-wise number and trend of dissemination of deep tube well technology in Bangladesh by the government (Source: Management Information Unit, DPHE, Dhaka, April 2013)

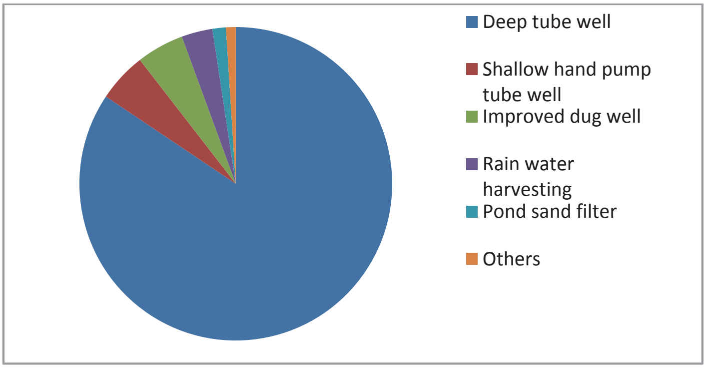

Figure 3.3: Deep tube well alone provides 84.4% of arsenic mitigation (Ravenscroft et al., 2009; DPHE & JICA, 2009)

3.4.1. Technological attributes of deep tube well

Originally, a deep tube well was a manually operated drilled well like the shallow hand pump tube well, except that it pumps water from a depth of 150 metres (See Figure 3.4). The UNICEF Number 6 hand pump (with suction mode) was the widely used hand pump model for shallow hand pump tube wells. For many years, these deep tube wells used to attach an Indian Mark II hand pump to a Number 6 pump-head, which did not perform well. As part of research and development, Tara, Tara II and Tara Dev (force mode hand pump) were developed, of which Tara (direct vertical action) was not appreciated by the women users because of the difficulty entailed in pressing down the handle. Along with Number 6 pump-head, Tara Dev (liver action) has been installed in the arsenic contaminated areas of Bangladesh. All the materials necessary for deep tube well and shallow hand pump tube wells were the same, although few modifications have been made over time. These included substitution of Poly Vinyl Chloride (PVC) for galvanized iron pipe for well casing and PVC buckets instead of old leather buckets. Otherwise, all other materials —seat valves, nuts, bolts, and cement for contraction of platforms— remained the same.

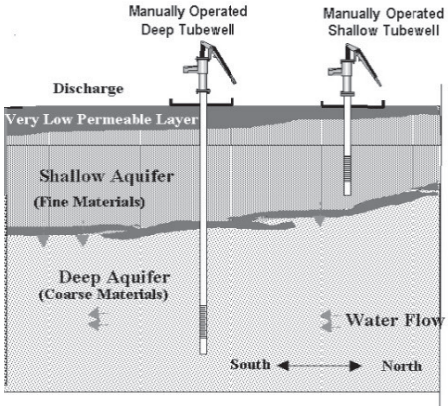

Figure 3.4: Technical design of deep tube well(> 150 metres) and shallow hand pump tube well (<45 metres) (Source: Ahmed, 2002)

Regarding installation issues, the “sludger method or hand percussion drilling” method that was useful for installing shallow hand pump tube wells needed to be replaced by a “direct circulation rotary drilling locally known as donkey drilling” method to drill a deep tube well, which is more costly. The workshop[9] with practitioners highlighted the technical advantages of deep tube well technology: i) it could provide safe drinking water without any further treatment; and ii) no electricity input was required. Female participants in the focus group session[10] revealed that deep

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[9] Author organized a workshop on January 7, 2012 at ShahrastiUpazila Chairman Office.

[10] Author organized a focus group session with female participants on December 25, 2012 at Uttar Suchipara village.

tube well had technical supremacy over other arsenic mitigation technologies, referring to a community level arsenic removal plant[11] that required chemicals and electricity. All the respondents in the workshop recognized that deep tube well technology was not entirely new to them. Hence, we found that deep tube well technology is perceived to be an incremental (modified or updated) version of existing shallow hand pump tube well, with competitive advantages over other arsenic mitigation technologies.

Therefore, with the introduction of the deep tube well in mitigating the arsenic crisis, key regime actors did not trigger any major changes to the regime. This deployment thus did not have to contend with uncertainties associated with technological attributes of radical innovations, with implications for user practices.

3.4.2. Adaptation in user practices and application domain (market)

One deep tube well is able to serve at least 10 households; hence it is seen as a community-level technology. Our survey (see Table 3.2) shows that 73.70% of the users knew how to use the deep tube well, whereas 67.7% users were comfortable with its design. The technology was seen as simple to operate by 65.7% users, and 56.6% appreciated its easy maintenance. Although only few (2.8%) users received training in use of this technology, and only 21.2% of those surveyed were concerned about arsenic contamination, a major proportion (92.8%) of users believed that the water they drank from the deep tube well was arsenic safe. Similarly, 75.8% of users found the deep tube well technology able to meet drinking water demand of households. In addition, 96% of users started using deep tube well willingly. It was, however, graded as labor intensive by a majority of users (75.8%). During summer, when water levels are low, the task of drawing water through pressing the handle was seen as laborious for female users, with the amount of pumped water also falling. An NGO official[12]mentioned that these problems are not new, however, as users had similar experiences with using shallow hand pump tube wells as well.

Using a community-level technology, such as the deep tube well, required a shift from a ‘private' individual source of safe drinking water to a shared source, as mentioned by the users[13]. In addition, this shift was often time and labour consuming, putting additional burden on women, who were traditionally responsible for managing drinking water. Users also agreed, however, that the installation of more deep tube wells within a neighbourhood had started to reduce this burden in recent years. An engineer[14] mentioned that this shift from household to community-level use was challenging for female users, but it was not entirely new in terms of existing safe drinking water practices. For example, one-third (29.3%) of the deep tube users had to collect drinking water from adjacent neighbourhoods previously, given that they had no shallow hand pump tube well in their own household.

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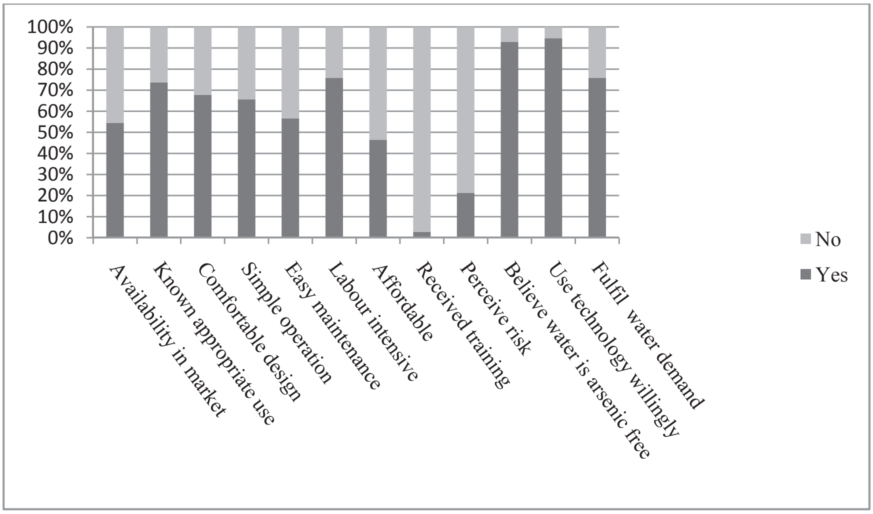
[11] One Sidko arsenic plant was installed at Uttar Suchipara union in 2003 by two voluntary organizations.

[12] Author interview with BRAC manager on January 12, 2012 at Shahrasti BRAC office.

[13] Author organized a focus group session with female participants on December 25, 2012 at Uttar Suchipara.

[14] Author interview with a DPHE engineer on December 29, 2012 at Shahrasti DPHE office.

Table 3.2: Selected variables relevant to user practices by the deep tube well users (N=99)



We find that evolving user practices with deep tube well technology are largely aligned with existing practices, in place for shallow hand pump tube wells. One additional aspect relates to affordability and existing practice regarding costs of securing safe drinking water. Since the installation costs of deep tube wells are high (US$ 900), 46.5% users found it affordable only when it was highly subsidized by the arsenic mitigation projects. Therefore, market actors had no direct connection with users unless the implementing agencies (government or NGOs) mediated between them. However, we identified fifteen incidences where rich families installed deep tube wells in their households by spending private money.

With regard to this situation, the owner of a hardware shop[15] found a similarity with the early days of disseminating of shallow hand pump tube well, when the government and NGOs procured the technologies to supply to the users in a similar way. An expert[16] mentioned that the market should directly be involved with the dissemination of deep tube well technology because it costs much less per capita than other arsenic mitigation technologies. As such, the unit cost of deep tube well technology (0.151 US$/m^3) is much lower than other arsenic mitigation technologies, for instance, 0.407 US$/m^3 for piped water supply and 0.353 US$/m^3 for removal or treatment technologies[17]. Our findings reveal that despite its high public demand as an arsenic mitigation technology, high capital cost involved with the installation serves as a hurdle in establishing a direct link between users and the market. In terms of arsenic mitigation, however,

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[15] Author interview with owner of a hardware shop on January 19, 2013 at Shahrasti.

[16] Interview with an expert of UNICEF on March 9, 2012 at Dhaka UNICEF office.

[17] http://siteresources.worldbank.org/EXTWAT/Resources/4602122-1213366294492/5106220-1213389414833/11.2Technology_for_Arsenic_Mitigation.pdf

project-based dissemination played a crucial role in the growing dominance of deep tube well technology as the mitigation option of choice.

Our discussion above highlights that key regime actors responded to the arsenic crisis through facilitating adaptation in user practices (community level of use) and the application domain (a linkage between users and market through project-based dissemination) in promoting deep tube well technology. These aspects have been discussed in existing literature (see Inauen et al., 2013; Hossain & Inauen, 2014) but more in the context of a comparative assessment of the acceptability of different arsenic safe technologies, rather than as diverse dimensions of an existing safe drinking water regime, as we do here. Our discussion also suggests a process of reorientation and adaptation within this existing sociotechnical regime, as a consequence of the introduction of the deep tube well, rather than a full-scale transition.

3.4.3. Symbolic meaning attached to the deep tube well

We also assessed the symbolic (cultural) meaning of the deep tube well, as manifested in the interaction between users, the media, engineers and implementing agencies. An engineer[18] noted that the shallow hand pump tube well was perceived by rural populations as a symbol of a 'technological miracle' and 'progress', an image promoted by the media, government actors and NGOs. As such, no rural household could imagine not having such a shallow tube well. However, this symbolic meaning changed with the advent of arsenic contamination in shallow tube wells. With this development, however, the deep tube well came to be similarly symbolized by the rural people as a 'technological miracle' for its ability to deliver 'safe' and 'farm-fresh' drinking water. Community representatives[19] who participated in the workshop argued that safe drinking water would be available for all through a simple technology like the deep tube well that did not require any further treatment, as did other mitigation options. Male respondents[20] considered drinking water as the grace of God, natural, non-contaminated, unlimited, and available for all without extensive operation and maintenance costs.

Practically, the deep tube well was the only technology offering such a profile, similar to the shallow tube well. As with the shallow tube well, users came to associate the deep tube well with social status and improved quality of life. For example, a proverb stating 'marry your daughter to a person with a tube well' remains very popular in rural areas, indicating the cultural value of tube well technology as it is embedded in rural life. Referring to the successful campaign on television and radio to promote shallow hand pump tube wells, one media expert[21] argued that rural people came to associate safe drinking water technology with a tube well. Due to a user's longstanding experience and interaction with tube well technology, it became an integral part of rural livelihoods.

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[18] Author interview with a DPHE engineer for arsenic mitigation on December 29, 2012 at Dhaka DPHE office.

[19] Author organized a workshop on January 7, 2012 at Shahrasti Upazila Chairman Office.

[20] Author organized a focus group session with male participants on November 19, 2012 at Uttar Suchipara.

[21] Author interview with a media expert on October 14, 2013 at Dhaka.

Our findings highlight that the symbolic meaning of the deep tube well is inextricably linked to earlier perceptions of the shallow hand pump tube well in rural society, which contributes to ensuring its dominance vis-à-vis other alternatives. With regard to identifying change mechanisms, our findings suggest that changes induced by introduction of the deep tube well to this dimension of the regime were characterized, again, by reorientation and restablization, i.e. adaptive transformation, rather than full-scale transition, of the socio-technical regime.

3.4.4. Reorientation in infrastructure

Infrastructure refers to the organization of associated activities related to dissemination of deep tube well technology within arsenic mitigation and rural water supply projects. The DPHE organized the bulk of the deployment of the deep tube well technology, as the government was primarily responsible for providing safe drinking water to rural populations. The allocation of the deep tube well was done in a top-down way, with decisions made by the DPHE head office. The Union wise allocation of deep tube well was executed by DPHE Upazila (administrative sub district) office, following the recommendations of the Upazila water, sanitation and hygiene (WATSAN) committee[22]. Similarly, village-wise allocation was administrated by the Union's WATSAN committee, under which Union Parishad (UP, elected body of the lowest administrative unit of local government) mobilised a ten-member water user group and obliged it to select a suitable spot for installing a deep tube well for community-level use. The workshop[23] revealed that it was not possible by DPHE to allocate deep tube wells to poorer families, without also involving the influential wealthier families. In this regard, UP developed an informal mechanism for group formation by including a rich family in the group as a host household, who would take on the responsibility to finance part of the installation, operation and maintenance costs of the technology. In doing so, the UP sought to mitigate power conflicts among the local actors, and also ensured the long term sustainable use of the deep tube well technology.

Once an installation spot was selected and the community paid the amount for cost-sharing (US$ 58-63), a formal agreement was made between UP, the water user group and DPHE. In line with this, one supplier (often a contractor affiliated with DPHE) hired drillers to install the deep tube well. The entire set of activities related to installation of a deep tube well was coordinated by the UP, DPHE and the host household. After the installation of the deep tube well, a water user group was made responsible for continued operation and maintenance. An elected representative[24] mentioned that despite relatively loose links between technicians and users, the maintenance of deep tube wells in post-installment period was not hampered as it did not require regular maintenance.

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[22] Upazila Water, Sanitation and hygiene (WATSAN) committee, consists of 23 members where Upazila chair and sub-assistant engineer of DPHE performs as president and secretary respectively. UP chairs, concerned government officers and representatives from NGOs are included as members. The Union WATSAN committee consists of 17 members and is headed by UP Chair.

[23] Author organized a workshop on January 7, 2012 at Shahrasti Upazila Chairman Office.

[24] Author interview with UP chair on November 11, 2012 at Uttar Suchipara.

Our findings reveal that this organizational infrastructure, consisting of water user groups, host households (caretakers), Upazila and Union-level WATSAN committees, and the DPHE favored the dissemination of deep tube well in arsenic affected areas. All these actors had long been involved in disseminating shallow hand pump tube wells, in the pre-arsenic contamination era. In the 1970s, Union board members —an administrative unit comprising several villages— were involved in the dissemination of shallow hand pump tube wells by DPHE (Black, 1990). Similarly, during 1973-74, the Dhamrai pilot project involved a UP to manage cost sharing and supervise installation of shallow tube wells, although with somewhat limited success (Black, 1990).As such, a new system of maintenance was introduced in 1976, in which a caretaker (selected from 10 user households) received training under an extension of the DPHE programme to NGOs (Black, 1990). Furthermore, the provision of cost-sharing was firstly introduced in 1976, when users contributed 50-75%of the installation cost.

The government and donor agencies deliberately introduced a cost sharing strategy in which users were entitled to claim their collective ownership of the tube well, by sharing partially in the costs. The cost sharing strategy was completely new in the safe drinking water sector when the hand pump tube well technology was introduced at the community level, long before the arsenic crisis. With the introduction of the low-cost shallow tube well, private ownership became popular. Once the arsenic crisis hit, a cost sharing strategy was re-introduced with the dissemination of the more costly deep tube well technology. One reason for this was that costs were is too high for a single household. This strategy proved to have two advantages. First, the government and donor agencies minimized overall project costs, as there was no separate budget available for operation and maintenance. Second, by covering 5% of total installation costs, and 100% of operation and maintenance costs, a group of 10 households shared the technology through which to mitigate the arsenic crisis, and developed a stake in it as a collective owner.

Our findings in this section highlight that actors previously involved in disseminating shallow tube wells now engaged in rapid dissemination of deep tube well technology in the context of arsenic mitigation by successfully reorienting existing organizational infrastructures to support this process. Thus, widespread diffusion of deep tube well technology was accompanied by adaptive transformation and restabilization of this dimension of the sociotechnical regime, rather than requiring a full-scale transition.

3.4.5. Industry involvement and structures

Implementing agencies disseminating the deep tube well received immense support from the existing industrial infrastructure around the shallow tube well, developed through interactions between tube well manufacturers and their suppliers. In 1970s, all the spare parts related to the manufacturing of tube well technology were imported from abroad. However, local foundry industries began to manufacture simple and sturdy cast iron workhorses for UNICEF No. 6 tube wells in 1975 (Black, 1990). Hardware shops in every small town were established to sell tube well spares and drillers, fitters, repairers and plumbers became available in every rural community. In 1987, the Mirpur Agricultural Workshop and Training School started manufacturing the Tara (direct vertical action pump) tube well to pump water from a depth of 15 metres. Along with Tara hand pumps, the company Aqua Engineering also started manufacturing hand pumps, including Tara II and Tara Dev. By 2000, there were 13-17 Tara hand pump producers operating in Bangladesh (WSP, 2000).

Our data[25] also shows that approximately 40 foundry companies were established to manufacture 30 designs (based on size and weight) of hand pumps suitable for both shallow and deeper depths. About 90% of the necessary cast iron is available in local markets, with the rest imported from India and China. Additionally, a shift from Galvanized Iron pipes to PVC plastic pipes in 1997 contributed to cost reduction of tube wells, according to a hardware shop owner[26]. Furthermore, widely established hardware shops and retailers throughout the country provided a number of services, including the supply of materials, transportation, installation and repair. Therefore, the existing industry structures enabled both users and implementing agencies to access the technology, with spare-parts available in the local market. This was confirmed by 54.5% of our survey respondents (Table 3.2).

According to a policy maker[27], the government, along with NGOs, nonetheless remained major buyers of deep tube wells, given that the installation cost remained higher (US$ 900) than a shallow hand pump tube well (US$ 130). It was also acknowledged, however, that the installation cost could be much lower (US$ 550-600) if individual households could procure the technology directly from local markets. For instance, in many areas affluent household shave started installing deep tube wells as shallow hand pump tube wells (even those not contaminated with arsenic) proved unable to provide sufficient water in the dry season.

In summary, our findings on this dimension highlight that the same industry structure in place to disseminate shallow tube wells now underpins the successful dissemination of deep tube well technology. No new arrangements were required to manufacture, supply and install deep tube well technology in the context of arsenic mitigation. As such, minimal regime reorientation and adaptation was necessary in order to secure the dominance of deep tube well technology.

3.4.6. Policies and practices

Another key dimension of the existing regime that we examine here is the policy context shaping dissemination of deep tube well technology. Several policies and government acts provided the institutional and regulatory context within which innovation and dissemination of deep tube well technology in the context of arsenic mitigation became successful. For example, the National Policy for Safe Water Supply and Sanitation (GoB, 1998) and the National Arsenic Mitigation

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[25] Author interview with human resource manager of Rangpur Foundry Limited on December 13, 2013 at Dhaka.
[26] Author interview with the owner of a hardware shop on December 23, 2013 at Dhaka.
[27] Author interview with policy maker of Policy Support Unit on July 25, 2013 at Dhaka.

Policy (NAMP) (GoB, 2004a) mandated the DPHE to play central roles in planning, implementing and maintaining the provision of safe drinking water options in rural contexts. In addition, the Local Government Act (GoB, 2009b) assigned the UP a direct role in supply, management and conservation of water resources. The National Water Policy (GoB, 1999) provided guidelines for the formation of community based organizations (for instance, water user groups) to maintain community water points. Furthermore, the National Industrial Policy (GoB, 2010) encouraged the establishment of tube well manufacturing industries with provision of tax holidays. The involvement of DPHE, UP, manufacturing industries and user groups were shaped by these policies.

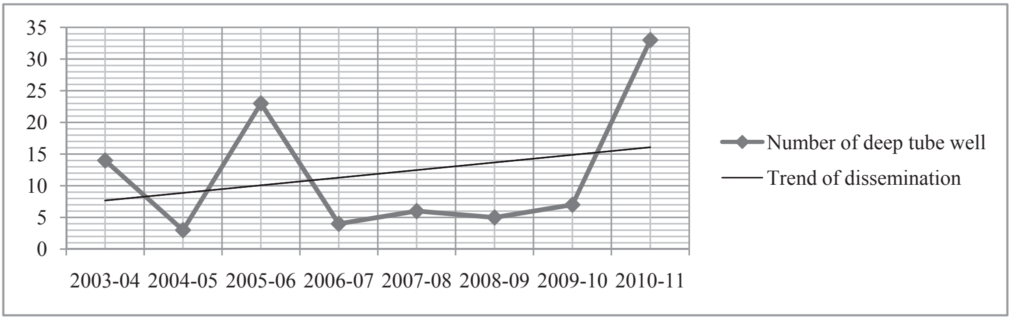

Figure 3.5: Year-wise number and trend of dissemination of deep tube well by DPHE at *Uttar Suchipara*Union. Source: DPHE office, Shahrasti, Chandpur, April 2013.

The NAMP resulted in an Implementation Plan for Arsenic Mitigation (IPAM, 2004) that advocated for certain preferred mitigation options. In particular, this implementation plan stated a preference for surface water technologies, including the improved dug well and pond sand filter. As per this plan, only if these two technological options were not deemed to be feasible in a given context, should the deep tube well be tried (GoB, 2004b). Such preferences were criticized however as being unsupported by adequate scientific evidence that improved dug wells, for example, could provide arsenic safe water. One scientist[28] argued that although surface water technologies could be arsenic safe in some areas, they showed high vulnerability to other contaminants (see also, Alam& Rahman, 2011). As a result, surface water technologies have mostly failed to have an impact upon arsenic mitigation. In practice, furthermore, the deep tube well technology was tried first, and a protocol for sinking deep tube well in arsenic affected areas was also adopted. Two recent policy papers reveal an official shift in preference for deep tube well technology, these include the recommendation for revision of the implementation plan; and the Sector Development Plan (GoB, 2009a, 2011).

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[28] Interview with a scientist on May 15, 2014 at Dhaka.

As another important element, a provision of cost sharing was required by all the relevant policies, such as the National Policy for Safe Drinking Water Supply and Sanitation (GoB, 1998), NAMP (GoB, 2004a), and IPAM (GoB, 2004b). Although IPAM restricted cost recovery mechanisms in the highly arsenic contaminated areas, it was found that a water user group consisting of 10 households contributed US$56 (about 5% of installation cost) for getting a deep tube well. Male focus group respondents[29] confirmed their support of this by noting that "provision of cost sharing for installation and maintenance (100%) ensures our combined ownership." Similarly, a DPHE engineer[30] and policy maker[31] confirmed that the government would continue disseminating deep tube well technology to ensure comprehensive access to safe drinking water in arsenic contaminated areas, wherever this option was technically feasible. Figure 3.5 shows annual installations of deep tube wells in Uttar Suchipara Union, indicating a growth trend similar to national growth trends (Figure 3.2). Additionally, the Bangladesh Rural Advancement Committee (BRAC), a national NGO, also disseminated 31 deep tube wells for community-level use in the same union.

Our findings highlight that national-level arsenic mitigation policies initially prioritized surface water technologies, yet in practice, installation and dissemination of deep tube well technology remained highly favoured (see GoB, 2009a; Ravenscroft et al., 2009). More generally, policies that had originally prioritized the shallow tube well proved supportive of deep well technology dissemination as well. We find therefore that regime actors successfully leveraged existing policies to ensure the dominance of deep tube well technology. This entailed again an adaptive transformation, rather than transition, of the socio-technical regime.

3.4.7. Supportive techno-scientific knowledge

Scientific evidence regarding the safety of available drinking water sources in the context of arsenic contamination has also been an important dimension of the sociotechnical safe drinking water regime, and one that has again supported widespread dissemination of deep tube well technology. A tube well deeper than 150 metres is widely acknowledged to be safe from arsenic contamination, as authoritatively claimed by a scientific report (BGS& DPHE, 2001). This report was considered a milestone in discussions around arsenic mitigation options (DPHE & JICA, 2009)[32]. As an engineer[33] from DPHE pointed out, available scientific knowledge enabled users to shift from the shallow tube well to the trustworthy deep tube well technology. The perceived trustworthiness of this option was also reflected in the user views: for instance, a majority of users (92.9%) believed that a deep tube well provides arsenic safe water (Table 3.2).

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[29] Author organized focus group session with male participants on November 19, 2012 at Uttar Suchipara.

[30] Author interview with a DPHE engineer for arsenic mitigation on December 17, 2012 at Dhaka DPHE office.

[31] Author interview with policy maker of Policy Support Unit on July 25, 2013 at Dhaka.

[32] Author interview with an expert on July 22, 2012 at Dhaka University.

[33] Author interview with a DPHE engineer for ground water on August 18, 2013 at Dhaka DPHE office.

Another aspect of required knowledge concerns that required for installation and use. Deep tube well technology is produced by manufacturing firms but is assembled and installed by drillers. The drillers do not require any new knowledge for installation of deep tube wells. One retailer[34]argued that no additional user knowledge was needed to operate and maintain a deep tube well. Furthermore, there was few technical uncertainties with regard to installation and use, if done according to the DPHE protocol. Local users were able to fix minor problems related with operation and maintenance, supporting again the dominance of the deep tube well as a preferred mitigation option.

In summary, on this dimension as well, our analysis shows that existing knowledge supported the dominance of deep tube well technology, with adaptive transformation (rather than transition) in the existing sociotechnical regime resulting from a more widespread use of this technology.

3.5. Discussion and conclusion

This paper started with the assertion that deep tube well technology has become the dominant arsenic mitigation option in rural Bangladesh. Earlier explanations of such dominance have focused on the technical attributes and social acceptability of this technology. In adding to these existing insights, we have sought in this paper to explain why and how the deep tube well has become the dominant arsenic mitigation option. We have done so by studying the magnitude of change occurring in seven dimensions of the existing safe drinking water socio-technical regime that have resulted from increasing use of the deep tube well, and the change mechanism underpinning these, in the specific context of arsenic mitigation in Bangladesh (Table 3.3).

We found that technologically, the deep tube well is an incremental version of the shallow hand pump tube well that was deployed long before the arsenic crisis emerged, but only in areas with salinity and low water tables. It has competitive advantages (for instance, a long life span, easy operation and maintenance, no requirement for water treatment etc.) over other arsenic mitigation technologies. Although evolving user practices with deep tube well were aligned with those of shallow hand pump tube wells, adaptation from ‘private' to ‘community’ operation was challenging. This challenge has gradually been overcome with a community management approach introduced by intermediary implementing agencies (Ahmadet al., 2006). Despite the huge public demand for the deep tube well in arsenic contaminated areas, high capital costs involved with its installation have prevented the establishment of a direct link between users and the application domain (market). In this connection, arsenic mitigation and safe drinking water projects implemented by the government and NGOs make this technology available to users through cost sharing. Like shallow hand pump tube well, the deep tube well secures its position as a ‘miracle technology’ that denotes a long-term assurance of safe drinking water. It is also synonymous with social status and progress in rural society.

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[34] Author interview with a retailer shop on November 23, 2014 at Dhaka.

Table 3.3: Explaining *transformation* of the safe drinking water socio-technical regime

Dimensions	Existing regime	Changes in dimensions of the regime of safe drinking water supply
Technology	Shallow hand pump tube well, with few deep tube wells for coastal areas and areas with low water table	Deep tube well as an incremental innovation that has competitive advantages over other arsenic mitigation technologies
User practice and application domain (market)	User practice supports household level of use. Users directly linked with market.	Adaptation to community level of use. No direct connection between market and users, implementing agencies mediate through arsenic mitigation projects.
Symbolic meaning	Tube well as a miracle technology, symbol of status and progress	Deep tube well has a similar symbolic meaning
Infrastructure	Managed privately, government and NGOs were involved.	Re-orientation through the involvement of DPHE, UP and users, no new infrastructure needed
Industry structure	Already developed, including foundry industries, hardware shops, masons.	No new industry structure was needed, adaptation of the provision for cost sharing.
Policies	Preference for installation of SHPTW, no restriction on deep tube well.	Although surface water technologies were preferred earlier, practically deep tube well was promoted.
Techno-scientific knowledge	29% shallow hand pump tube wells were found unsafe.	Deep tube well is a safer option for the arsenic contaminated areas, installation and use did not require new knowledge

Our findings also show that a re-orientation of existing infrastructure in which the UPs, water user groups, caretakers, and WATSAN committees are involved, has played a major role in dissemination of deep tube well technology in arsenic affected areas. One study (Ahmed et al., 2006) calls for excluding Ups from this infrastructure, given an assumed bias towards furthering the interests of the powerful. Our findings suggest, however, that such exclusion will not help the DPHE to reduce power conflicts among local actors in the process of allocating technologies and specifying their locations.

We also find that the existing industry structure established to manufacture shallow tube wells now also underpins the dominance of deep tube well technology. Additionally, no change in the existing industry structure is required to manufacture, supply and install the deep tube well in the arsenic contaminated areas. An interesting finding is that the NAMP and IPAM embody a preference for surface water technologies, because surface water is assumed to contain no arsenic (see also, Hossain & Inauen, 2014). In practice, however, the dominance of deep tube well in arsenic mitigation is secured by institutional, regulatory and financial support, regardless of support for surface water options in policy documents. In this, the provision of cost sharing has emerged as a core strategy in disseminating the deep tube well technology (see, for example, Ahmed et al., 2006; Sekar & Randhir, 2009; Johnston et al., 2010). Additionally, the commitment of the government to install a deep tube well within 150 metres from any household stimulates the dissemination of deep tube well technology (DPHE, 2013)[35].

Techno-scientific knowledge embodied within the deep tube well technology has also clearly supported its widespread dissemination. As such, the deep tube well technology has emerged as a problem-solving technology in the context of arsenic mitigation in Bangladesh. Our analysis reveals, furthermore, that these aspects of development of deep tube well technology and its embeddedness in the existing regime overlap with features of "incremental innovation"(see for example Harty, 2010; Sen & Ghandforoush, 2011). Several overlapping features of incremental innovations have been identified in our analysis, for example, that the deep tube well shares certain technological attributes with the shallow tube well; users are acquainted with its operation; existing industries are able to produce and supply the technology; no new technical knowledge is required; and uncertainty within markets is low.

Our analysis also sought to identify change mechanisms and the magnitude of change in seven regime dimensions, in the context of providing arsenic safe drinking water options. We find that with the introduction of deep tube well as an arsenic mitigation technology, no fundamental changes were required in the existing safe drinking water socio-technical regime, as reflected in its seven dimensions. Several of these dimensions, including technological attributes, symbolic meaning, industry structures, and techno-scientific knowledge are supportive of the dominance of the deep tube well. Besides, adaptation in user practice (a shift from "private" to community facilities), reorientation in infrastructures (through reorganization, without including new members) and introduction of policies and practices (through institutional, regulatory and financial supports) also helped to secure its dominance.

This analysis indicates that with the dominance of deep tube well technology, a *transformation* took place in the existing safe drinking water regime after arsenic contamination was discovered. Although deep tube well technology was introduced in Bangladesh well before the arsenic crisis emerged, and when the safe drinking water regime was still stable and configured around the shallow tube well, its resultant destabilization because of arsenic contamination helped to ensure a growing dominance of the deep tube well. Our analysis thus makes clear that interaction between the landscape level (arsenic contamination) and regime dynamics is a prerequisite for transformation. As such, and because the landscape level is involved here, we cannot conceptualize the evolution of the existing regime as *reproduction.* Reproduction as a change mechanism entails dynamics only within the regime level, rather than at landscape or niche level (Geels& Kemp, 2007).

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[35] DPHE (2013), Official Document, Retrieved from: C\Documents and Settings\USER\Desktop\Rupkolpo.11-12(Water Supply-1).doc, Accessed on: January 12, 2014.

Then the remaining question is why *transition* did not take place in this case. Firstly, the existing regime was not completely destabilized with the advent of arsenic contamination. Secondly, incumbent regime actors were able to adapt crucial dimensions of the regime in addressing the arsenic crisis. Third, although a number of radical innovations for arsenic mitigation (for e.g., the household Sono arsenic removal filter) emerged at the niche level, these failed to put pressure on the existing safe drinking water regime, wherein the incremental innovation represented by the deep tube well was becoming dominant.

Furthermore, due to pressure from outsiders, such as international development agencies and scientists, regime actors including the government of Bangladesh and NGOs deliberately promoted the dissemination of deep tube well technology instead of filter and treatment technologies as a priority to achieve one of the Millennium Development Goals[36] (Milton et al., 2012). Despite the prevailing debate in overall achievement of these goals, safe drinking water coverage in rural Bangladesh has been restored up to 84% from an earlier 72%, mostly due to the contribution of deep tube well technology to safe drinking water provision (see, for example, Rammelt et al., 2014). Our analysis clarifies that such changes did not trigger a transition in the existing safe drinking water regime, also because millions of shallow hand pump tube wells still dominate by providing safe drinking water in non-arsenic contaminated areas. We conclude that the deep tube well technology has emerged as an incremental innovation in the context of arsenic mitigation in Bangladesh, aligned with, and supported by, reorientations and adaptations in several dimensions of the existing safe drinking water regime. These reorientations and adaptations have served to both transform and re-stabilize the regime. In the same vein, the resilience of the existing safe drinking water regime reveals that it will be difficult for new arsenic mitigation technologies to challenge the dominance of the deep tube well.

In contrast to the literature on arsenic mitigation that presents the deep well tube as preferred technology because of its individual technical attributes or social acceptability, this paper has shown that social or technical performance alone cannot explain technological dominance. Various inter-related dimensions of the existing safe drinking water regime need to be supportive, or be adaptable, to secure the dominance of this specific technology. We conclude as well that the application of incremental innovation in a developing country context is useful, even when an existing regime is less stable. Our analysis contrasts with the existing assumption within the Multi-Level Perspective that incremental innovation performs well only in a stable regime (See for example Geels & Kemp, 2007). As such, our analysis highlights the context specific conditions under which the multi-level perspective on transition has explanatory power in developing country contexts.

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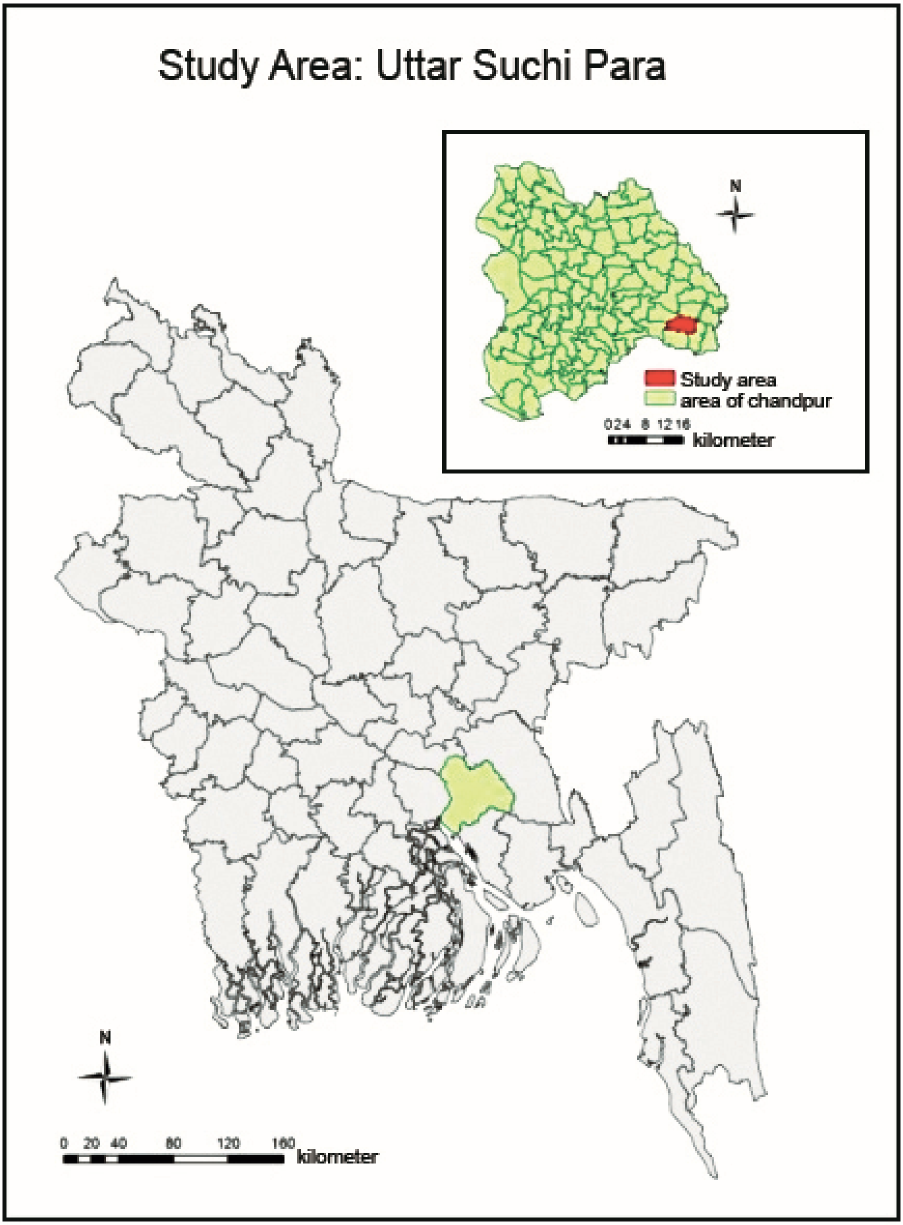
[36] Target 7c states ‘halving by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation’ retrieved from: https://sustainabledevelopment.un.org/content/documents/981bangladesh.pdf

In addition, our analysis contributes to the existing literature on arsenic mitigation in Bangladesh, by offering an integrated analysis of regime dynamics and change mechanisms, with an emphasis on a particular technological innovation. Specifically, identifying transformation as the change mechanism through which the deep tube well has become dominant is a concrete contribution of our paper. This study also yields insights for arsenic mitigation policy implementation; in particular, by reaffirming that incremental innovations remain critically important to mitigating the arsenic crisis in Bangladesh.

Appendix 1: Study area



Chapter 4

Failing Arsenic Mitigation Technology in Rural Bangladesh: Explaining Stagnation in Niche Formation of the Sono Filter

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Abstract

Arsenic contamination of shallow hand pump tube well drinking water in Bangladesh has created opportunities for radical innovations to emerge. One such innovation is the household Sono filter, designed to remove arsenic from water supplies. Applying a strategic niche management approach, and based on interviews, focus groups and a workshop, this article explains the Sono filter's failure to establish itself as a successful niche technology. Three explanatory factors are identified: lack of a strong social network (of technology producers, donors, users, and government actors) around it; diverging expectations regarding its potential to be a long-term solution; and lack of second order learning amongst key actors. Beyond these three factors that help to explain the lack of successful niche formation, this paper clearly shows that the overwhelming dependency on fund-driven projects also deters successful niche formation in the context of the developing world.

4.1. Introduction

Providing safe drinking water to all remains a pressing global imperative, with the water sector, and associated water governance arrangements, having to contend with various long-acknowledged environmental, hydrological and technological uncertainties and challenges (Ahmed, 2002; Biswas & Tortajada, 2010). One such pressing human health crisis relating to lack of safe drinking water is the extent and severity of arsenic contamination of rural drinking water supplies in Bangladesh. As noted by various studies, approximately 1.4 million out of 4.8 million shallow hand pump tube wells tested in the country are contaminated with arsenic levels above the safety limit of 0.05 mg/L (Ahmed et al., 2006; Johnston & Sarker, 2007). As a result, safe drinking water coverage in rural areas of Bangladesh has dropped from 97 percent to 72 percent since 1993 (Smith et al., 2000) and 57 million people were estimated to be at health risk of drinking arsenic contaminated water above 0.05 mg/L (Shafiquzzaman et al., 2009; Chakraborti et al., 2010).

In response, the government of Bangladesh, non-governmental organizations (NGOs), and international donor agencies have been involved with several arsenic mitigation efforts, to provide safe drinking water to millions of rural people. In addition to focusing on options to provide alternative sources of safe drinking water, arsenic removal technologies have also been central to such mitigation efforts (Boerschke & Stewart, 2001; Pal et al.,2011; Rammelt et al., 2014).

In this article, arsenic removal technologies are considered to be a radical innovation, because these new technologies require adoption of new water use practices and do not fit easily into the existing socio-technical safe drinking water system in rural Bangladesh. In the category of household arsenic removal filters, four of the five household filter systems approved by the government of Bangladesh in recent years have been imported from foreign countries and can hardly be found anymore in rural Bangladesh. The household-level Sono filter, however, is an exception, it is a simpler local technological innovation, developed and manufactured in Bangladesh from locally available materials, even has it has received praise from the international scientific community, and initially appeared to be a very promising arsenic mitigation option (Hussam et al., 2008).

Despite national and international recognition of its social, economic and technical performance, the Sono filter's initially promising uptake and use has stagnated over the last decade, with the number of filters in use and the area covered remaining low. This process of stagnation has not, however, been systematically researched. This paper aims to explain how and why the initially promising take-off of the Sono filter stagnated, and assesses the possibility of its further diffusion and uptake. Through applying a strategic niche management (SNM) perspective, the activities contributing to niche formation (or lack thereof) of the Sono filter are analyzed, relating both to its production (manufacturing) and dissemination (procurement, distribution/diffusion and monitoring). Such an analysis can shed light on the processes and preconditions for successful niche formation in developing country contexts.

Section 4.2 discusses further the multi-level perspective (MLP) and SNM theory, wherein niche formation is seen as a crucial first step in the take-off of socio-technological (radical) innovations. Section 4.3 introduces the research methods used, followed by the analysis of experimentation with the Sono filter in specific districts in rural Bangladesh (Section 4.4). Section 4.5 explains the process of niche formation and stagnation, followed by discussion and conclusion (Section 6).

4.2. Conceptualizing niche formation

In theoretical terms, four frameworks could have been used to analyse the promise of the Sono filter as a radical innovation in arsenic mitigation in rural Bangladesh. These include Transition Management, Technological Innovation System, Multi-level perspective and Strategic Niche Management (Markard et al., 2012). Transition Management is a practice oriented model that provides insights for influencing transition process at local or regional context, whereas Technology Innovation System identifies drivers and barriers of innovation and helps to develop technology-specific policies (Markard et al., 2012). In this paper, we have used Multi-level perspective (MLP) and Strategic Niche Management (SNM) because MLP proved useful for contextualizing SNM (Schot & Geels, 2008) in which the innovation journey of a technology can be understood by studying niche formation.

The MLP is part of transition theory, and has been formulated and utilized to explain how major socio-technological change takes place, through analyzing interactions across three different levels (Schot & Geels, 2008; Wieczorek et al, 2015). The highest (macro) landscape level consists of rather inert contextual conditions against which specific socio-technological change takes place. Socio-technical regimes form the second (meso) level, and are conceptualized through seven dimensions: technology, user practices and application domain, symbolic meaning of technology, infrastructures, industry structure, policy and technological knowledge (Geels, 2002; Schot & Geels, 2008). Lastly, niches at the micro level refer to protected spaces, wherein radical innovations emerge, receive support and are nurtured against mainstream market selection and the prevailing regime (Kemp et al., 1998; Raven, 2006).

The MLP of transition theory provides a lens to analyze and understand how niche formation processes takes place, and how they are structured, enabled and contextualized by landscape and socio-technological regimes (Schot & Geels, 2008). In niche formation processes, niche innovations are produced, developed and diffused, and finally included in socio-technological regimes. While niches are structured and enabled by sociotechnical regimes and landscapes, this is not a one-way influence. Niches also can and do change existing socio-technological regimes and landscapes. To explain such interactions, Strategic Niche Management (SNM) has been developed to analyze and guide the emergence and application of a radical innovation. Practically, SNM facilitates learning about how the rate of innovation application and uptake can be enhanced (Kemp et al., 1998; Schot & Geels, 2008).

The MLP also emphasizes that radically new technologies do not emerge suddenly, but are related to developments at the level of semi-stable regimes and landscapes. This is also the case with the Sono filter. The prevailing safe drinking water regime in Bangladesh became destabilized by the discovery of widespread arsenic contamination in existing drinking water sources, primarily the shallow hand pump tube well. Hence the regime needed adaptation and change (i.e., innovation) in order to fulfil its conventional safe drinking water functions for the rural population and thus to become stabilized again. Different actor networks experimented with developing and institutionalizing a variety of niche innovations relating to drinking water production and consumption. The Sono filter was one of the niche innovations that emerged following the partial destabilization in the existing safe drinking socio-technical regime resulting from the discovery of arsenic contamination (see Figure 4.1).

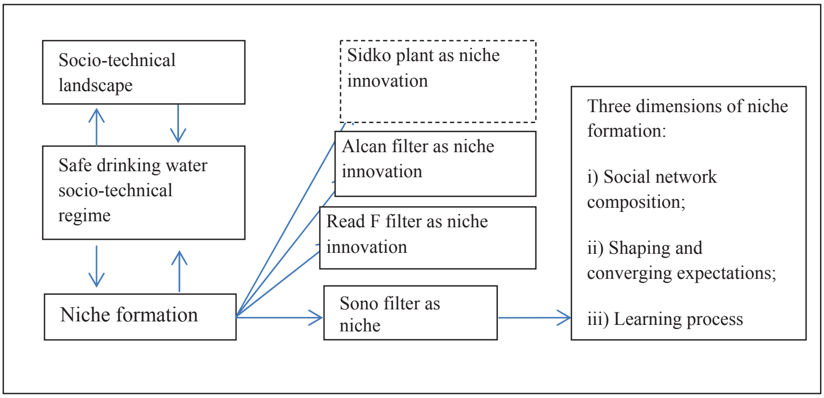

Figure 4.1: Conceptualizing three dimensions of Sono filter niche formation

According to SNM, niche formation is often decisive to start a major socio-technological change, but only a *few* niche innovations are widely disseminated and/or result in a socio-technological regime shift. A niche innovation is successful when it is included in, and thus helps to change, the existing socio-technological regime, so that it can again fulfil its (conventional or new) functions. But measuring success of niche innovations is not a straightforward task. The initial goal of a niche innovation is to solve problems that the old regime was unable to address. In the case of arsenic contamination of drinking water in Bangladesh, the old socio-technological safe drinking water regime was unable to continue to provide rural Bangladesh is with safe drinking water. Hence, success would require a niche innovation to change the regime in a manner that aids in providing safe drinking water again.

Successful niche formation can be assessed by exploring three dimensions: the composition of the actor network supporting the niche innovation, the shaping and convergence of expectations regarding the niche innovation by actors in the network, and learning processes that take place by actors using the niche innovation (Kemp et al., 1998; Geels, 2004; Raven, 2006).With respect to the first dimension, the broader and deeper the *social (actor) network* around the niche innovation is, the more the network will be able to contribute to niche production and diffusion of innovation, and thus to regime adaptation and change. A broader network refers to the number of relevant actors and stakeholders involved in niche formation, while a deeper network refers to the degree to which network actors are able to mobilize relevant resources for niche formation (financial resources, technological skills, time, knowledge, administrative or market power, etc.). Secondly, the more *expectations* of various network actors converge regarding the benefits of the technological niche innovation, the more niche formation is advanced and able to influence the socio-technological regime. For that expectations need to be robust (shared by many actors), specific (in that they provide guidance in innovation), and of high quality (meaning that the content of expectations is demonstrated by on-going projects). Thirdly, *learning processes* contribute to niche formation. First order learning refers to learning about technological and economic solutions within the framework of existing values and goals (Smith, 2010). More important is second order learning, where learning involves changes in values, goals, new actor roles and new relationships that make niche formation successful (see, Schot & Geels, 2008; van Mierlo, 2012).

To understand and explain how and why the Sono filter niche innovation stagnated after an initial take-off, and thus did not change the destabilized safe drinking water regime towards a new (re-stabilized) regime, these three niche formation dimensions are analyzed (see Figure 1). In analyzing the performance in niche formation, actors are divided in two categories: core niche actors and hybrid actors (which are basically regime actors who can also play role in niche formation)(Kemp et al., 1998; Schilpzand et al., 2010).

4.3. Methods and approaches

To understand the failure of the Sono filter in contributing to re-stabilizing the socio-technological drinking water regime after the arsenic crisis, a case study methodology was followed, using mainly qualitative data collection methods. Kushtia, a north-western district of Bangladesh was selected as the case study area. There were several reasons for this choice: i) shallow hand pump tube wells in the area are contaminated by arsenic; ii) Sono filter has been introduced and was available in the field during the research; and iii) the head office of the only manufacturing firm for the Sono filter (the core niche actor)is situated in Kushtia.

Different data collection methods were used. Most importantly, primary data was collected from various actors involved with Sono filter niche formation through individual in-depth interviews, focus group sessions and a workshop (see Table 4.1 and below). Furthermore, primary and secondary data were obtained from other sources, such as websites of implementing NGOs, donor agencies and governmental organizations, conference proceedings, official documents and workshop reports. Data were collected between October 2011 and December 2014. With this data collection, we expected to identify the historical evolution of Sono filter development in Bangladesh. By 2014, it was clear that (experimental) diffusion and use of the filters in the field was already stagnating. As such, such an ex-post analysis offered opportunities to reflect on alternative ways for successful niche formation.

Data collection activities centered around the three core niche formation concepts − social network composition, sharing and converging of expectations, and learning processes – with additional questions relating to Sono filter manufacturing, funding, procurement, distribution, and use. The relevant actors for interviews were identified following their role in niche formation processes: niche actors (innovators, manufacturers, promoters and buyers of Sono filter) and hybrid actors (users, policy actors, experts, approval agency, non-governmental organizations, international donors and governmental organizations).

Table 4.1: Participants in interviews, focus groups and workshop.

Data collection method	Respondents and participants (in number)
In-depth interviews	*Niche actors:* 12 with MSUK (with several follow up meetings) 12 with NGOs and one with DPHE (institutional buyers) *Hybrid actors:* 4 with international development agencies: UNICEF, JICA and WHO 3 with scientists and experts (with follow-up meetings) 4 with national NGOs working in water sector 7 with policy actors 11 with Sono filter users 6 with local government institutions 4with DPHE engineers as mandated state agency for arsenic mitigation
Focus group sessions	*Hybrid actors:* 3FGs with 30 Sono filter users
Workshop	15 niche and hybrid actors including MSUK, other NGOs, DPHE, local government institutions, community representatives and users

Manob Sakti Unnayan Kendro (MSUK), a local NGO, is the core niche actor in Sono filter innovation, because it was responsible for the production, supervision, marketing and dissemination of Sono filters (Hussam et al., 2008). A total of twelve in-depth interviews (in several follow-up meetings) were conducted with different officials of MSUK. Besides, thirteen in-depth interviews were held with institutional buyers (involved in dissemination) such as NGOs and the Department of Public Health Engineering (DPHE), following the list provided by MSUK. In addition, four in-depth interviews were conducted with the international development agencies (donors). Overall, a total of 39 in-depth interviews were carried out with other actors at both national and local levels who were thought to be influential in niche formation (see Table 4.1). Three focus group sessions with Sono filter users were organized (two with 20 female and one with 10 male participants) to gather data on availability, use, cost, quality of product and long term sustainability of the Sono filters. One workshop was organized to explore the support for, and challenges inherent in, Sono filter niche formation. This included a discussion on what could have been done differently by various actors to overcome the challenges related to Sono filter niche formation. Interview with MSUK officials provided information on manufacturing, procurement, product development, environmental concerns (e.g., disposal of sludge), interaction with donors and implementing NGOs and GOs, human resources, communication strategies and feedback mechanisms.

Besides, institutional buyers and implementing agencies provided insights on network building, feedback mechanisms, information dissemination about product installation, replacement, sludge disposal and markets, and their experience with donor-funded projects. Their suggestions to regularize the manufacturing and dissemination of filter were also explored. In addition, interviews with several hybrid actors, including donor agencies, experts, policy actors and engineers, revealed information on MSUK's possibility of getting funds to manufacture and disseminate the Sono filter, and also provided insights on the Sono filter's possibility to re-stabilize the safe drinking water regime in rural Bangladesh.

4.4. The rise and stagnation of the Sono filter in rural Bangladesh

Through a major joint effort by international development agencies, the government of Bangladesh, the private sector and (inter)national NGOs, a safe drinking water socio-technical regime in rural Bangladesh was established in the 1980s (Black, 1990). Central to establishing this successful and stable regime was the installation of about 10 million shallow hand pump tube wells that ensured biologically uncontaminated, safe drinking water to 97 percent of the rural population, a huge public health success for Bangladesh (Flanagan et al., 2012). The National Water Act of Bangladesh highly favoured the installation of shallow hand pump tube wells to provide safe drinking water in rural areas, as did many other water policies (GoB, 2013). In addition, an adequate industry structure that include foundry companies (producers of hand pump, spare-parts and pipes), hardware shops and expert masons enabled the rural people to buy and install shallow hand pump tube well technology at affordable costs: around US$ 100-140 per unit. Furthermore, during the 1980s and 1990s, a coordinated and compelling media campaign helped to motivate and educate rural citizens to install and use this technology. Available knowledge embodied within the technology was also effectively communicated to millions of users. As a result, shallow hand pump tube well technology became central to the rural safe drinking water regime, forming the symbol of progress in rural areas and gaining immense cultural value.

Many of these shallow hand pump tube wells became unsafe after the detection of naturally occurring arsenic contamination of ground water in 1993, which partially destabilized the safe drinking water socio-technical regime. The government realized that without addressing the arsenic crisis, one of the Millennium Development Goals would not be achieved: halving, by 2015 (compared to 1990), the proportion of people without sustainable access to safe drinking water and basic sanitation. Against this background, developing and implementing arsenic mitigation technologies was given high priority and approximately 20-40 arsenic removal filter technologies were experimentally developed as niche innovations (Ahmed, 2002; NAISU, 2003). The Sono filter was one of the more promising such innovations in Bangladesh.

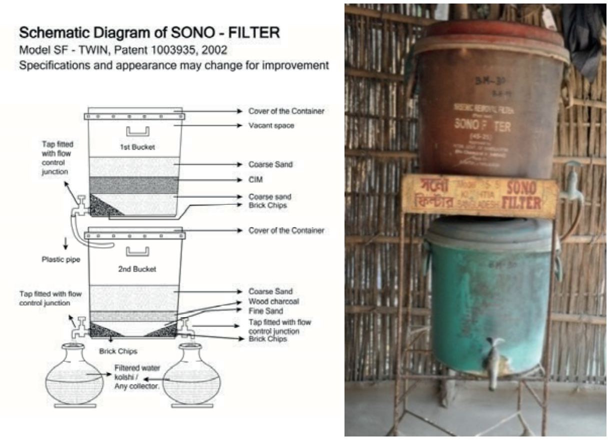

Figure 4.2: Schematic diagram of Sono 2-bucket filter (Hussam et al., 2008) (left); picture of Sono filter taken by one of the authors (right).

Abul Hussam, a Bangladesh born chemistry professor in George Mason University, United States, and A.K. Munir, a Bangladeshi scientist designed the first Sono 3-Kolshi (pitcher) filter in 1999 at KushtiaSono Diagnostic Centre. After several design modifications, Sono two-bucket filter (Sono 45-25 model) was developed in 2003 (Figure 4.2). This filter won the 2007 United States National Academy of Engineering-Grainger Challenge Prize for sustainability, which brought national and international attentionto the Sono filter (Hussam, 2009). It was designed for household scale use and costs US$ 50, while a filter media replacement costs US$ 10. Each Sono filter can produce 20 litres of clean water per hour and its guaranteed life span is five years (Johnston et al, 2010). The filter does not require any electricity to be operated, and all manufacturing materials are locally available in Bangladesh, including two plastic buckets, a tap, charcoal, river sand, brick chips, a metallic filter stand and a composite iron matrix (see Figure 4.2). This is why the Sono filter is considered a local technology, whereas other filters are mostly imported from foreign countries. The information displayed on the buckets includes the logo of the manufacturer MSUK (Manob Shakti UnnayanKendro), the patent number, a notice to mark government approval and guidelines for filter use. The process of filtration includes two steps: the first step removes arsenic in the top bucket, whereas the second step removes microbial contaminants as well as fine particles.

After obtaining the patent right and approval from the government, Manob Shakti Unnayan Kendro (MSUK), a local NGO founded by the inventor of the Sono filter, started manufacturing the filter and selling it commercially (Hussam & Munir, 2007). In order to facilitate dissemination of the Sono filter, MSUK developed a website. Based on several published documents and publicly available information provided by MSUK, it can be estimated that 225,000 filters had been manufactured by 2011, increasing to 276,350 filters by 2014 (Figure 4.3). Information by MSUK showed that institutional buyers (mainly NGOs, often using donor funds) procured around 73% of the totally manufactured filters till 2014, of which MSUK itself bought around 29% through its donor-funded projects (Figure 4.4)[37].

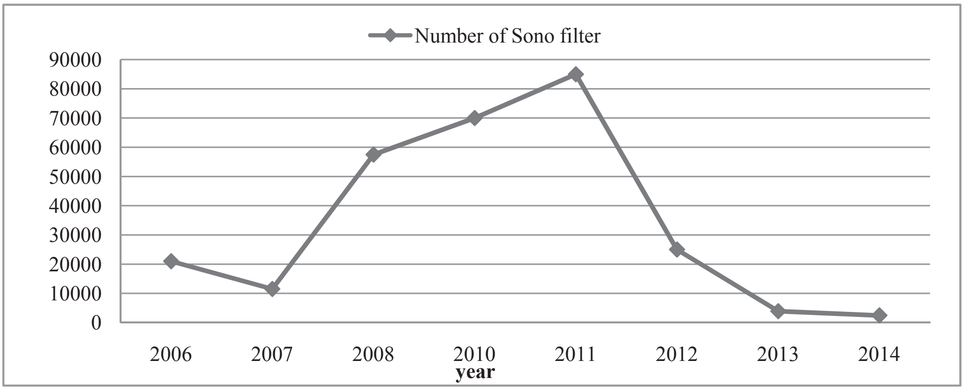

Figure 4.3: Yearly manufacturing of Sono filters

Although data on manufacturing and dissemination were not systematically collected, both Figures 3 and 4 illustrate that the manufacturing and dissemination of Sono filters declined dramatically after 2011. The take-off of the Sono filter had stagnated by 2012, as also confirmed by interviews with implementing NGOs. This is evident from three additional factors, including: first, the small contribution of the Sono filter to overall arsenic mitigation, in terms of number of households and area of coverage (only some villages in 18 out of the 61 arsenic contaminated

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[37] The projects were: Arsenic mitigation program for children at primary school (June 2002 - July 2003), Integrated program on arsenic mitigation and promotion of public health (August 2002- July 2006), Mitigation of arsenic disaster and promotion of public health at Kushtia and Meherpur districts (November 2005 - December 2008), Clean water for Bangladeshi people and school children (July 2008-December 2008) and Portable drinking water for the arsenic exposed poor people (July 2010-June 2011) (Source: MSUK, March 30, 2013).

districts) (DPHE & JICA, 2009)[38]. Second, the production and dissemination of the Sono filter was irregular, with large discontinuities (Figures 4.3 & 4.4). Third, most disseminated filters were abandoned before reaching their guaranteed life time of five years and were not replaced by new filters (Kabir & Howard, 2007)[39][40][41].

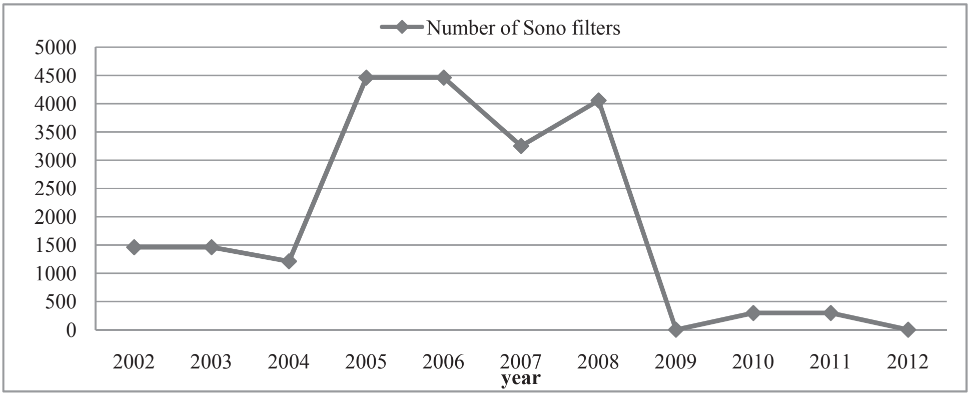

Figure 4.4: Year-wise average dissemination of Sono filter only by MSUK with support from donor agencies

4.5. Analysing stagnation in niche formation

In analysing why the Sono filter's initial take-off stagnated after some years, this section explores three dimensions of niche formation processes around the Sono filter: social network composition, shaping and convergence of expectations, and learning processes (see Table 4.2).

4.5.1. Social network composition

In the SNM literature, a broad and deep social network is considered crucial for successful niche formation. Initially (1999-2002), the Sono filter social network was small (including only organizations run by family members of the inventors, such as Sono Diagnostic Centre, Human

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[38] Approximately one million people have allegedly benefited from one-time installation of Sono filter, whereas the total number of people at risk was 57 million.

[39] For example, only three out of 100 Sono filters distributed in some Bangladeshi villages were still in use two years after they were acquired. Retrieved from: www.echoinggreen.org/fellows/minhaj-chowdhury, Accessed on: December 13, 2014.

[40] The figure was compiled from information obtained from multiple sources:
http://www.irinnews.org/report/76176/bangladesh-new-water-filter-to-combat-arsenic-poisoning,
http://www.gmu.edu/depts/chemistry/CCWST/SONO%20Filter-%20A%20Solution%20for%20Arsenic%20Crisis%202013.pdf,
http://www.designother90.org/solution/sono-water-filter/, the daily star, MSUK & Hussam*et al.*, 2008.

[41] Donor agencies: Die Licht Brucke (DLB) of Germany, Good Gift Catalogue (GGC) of United Kingdom and the Federal Ministry of Economic Cooperation and Development, Germany.

Development Research Centre, Quashem-Nahar Trust Fund); but this network succeeded in supporting early research and development activities (Table 4.2). Besides, an international research network provided support for the further improvement of the filter, including George Mason University, the University of Maryland, the University of Dhaka and the Swiss Federal Institute of Aquatic Science and Technology. Finally, the certification from the Bangladesh Council for Scientific and Industrial Research (BCSIR) enabled MSUK to carry out commercial production, marketing and dissemination of the Sono filter.

During 1999-2002, the establishment of MSUK, a Kushtia-based local NGO chaired by a Sono-filter (co)inventor and his brother, was an important stepping stone to facilitate niche formation activities. MSUK managed to develop a small but effective manufacturing network that encompassed a manufacturing plant at Kushtia, the Bipasa plastic company (for producing plastic buckets), local suppliers (for delivering charcoal, river sand, iron and brick chips) and local welding workshops (for the metallic stand). Generally, suppliers were asked to deliver materials on demand, after MSUK received procurement orders from institutional buyers (NGOs). With 27 staff, MSUK had the capacity to (manually) produce 200 filters per day in an eight hour slot. Once a filter was assembled, the flow rate and composition of filter media was checked before it was delivered to the buyers. The coordinator and project staff monitored procurement, manufacturing and transportation, whereas the chairman of MSUK maintained overall supervision. As filter transport required special care, an agreement was made with a local courier service which used flatbed rickshaws, trucks and boats as modes of filter transportation.

Table 4.2: Sono filter niche formation

Time period	**Dimensions of niche formation**		
	Social network	**Shaping expectations**	**Learning processes**
1999-2002	Innovators ,Sono Diagnostic Centre, HDRC, One trust fund	From Sono three-Kolshi to Sono two-bucket model	Modification of filter, cost sharing, launching of website, transportation and handling of filter
2003-2008	Sono Diagnostic Centre, MSUK, plastic company, welding workshop, local suppliers, transporters, NGOs, foreign donors, DPHE, users	Expectations initially converged because projects were available; but community level non-filter technologies preferred by policy actors	Space for second order learning under several projects, but preoccupation on short term benefits
2009-2011	MSUK, NGOs, foreign donors, users	Expectations diverged as number of projects declined, filters considered a short-term solution and less user-friendly by disseminators	Hardly any second order learning by users and MSUK
2011 onward	MSUK, only few NGOs, manufacturing becomes uncertain	No platform remained for shaping expectations, in the absence of new projects	No platform for facilitating learning processes, in the absence of projects

Besides a very limited number of individual buyers, three kinds of institutional buyers articulated demand, according to MSUK. These included: i) 17 NGOs(including many partner NGOs who worked in collaboration with national NGOs)bought filters with international donor support[42]; ii) the governmental agency DPHE bought filters with UNICEF support; and iii) foreign organizations directly bought filters (such as Filters for Families, Nepal; Hania enterprises, Pakistan)[43].In all cases, institutional buyers contracted with MSUK to procure a certain number of filters, funded by the donors, only for a limited time period. Although the buyer network seemed broad, only few NGOs continued to procure filters after 2011. Similarly, DPHE did not renew its contract after considering that the filter was not feasible for long term use, cost was very high, and the post-deployment monitoring was troublesome. For the same reasons, as mentioned by implementing agencies, donors were hardly willing to promote the Sono filter further. Hence, this procurement network with governmental organizations, NGOs and international donors could not evolve into a stable partnership and proved not instrumental in niche formation. Several governmental and international actors (e.g. DPHE and UNICEF) discontinued their role in Sono filter niche formation. Similarly, many crucial NGOs (e.g. NGO Forum for Public Health, Asia Arsenic Network, Water Aid Bangladesh) supported and disseminated other mitigation technologies and were mostly absent in the Sono filter social network. Other development NGOs that once procured Sono filters (e.g. BRAC, Jagoroni Chakro Foundation, Rupantor, Nijera Kori, Dipsetu and World Vision) noticed that MSUK never contacted them and lost interest to promote filter. Overall, interviews with eleven implementing NGOs confirmed that MSUK never asked feedback for further development of filter and its dissemination. Similarly, environmental NGOs, the media and local governmental agencies never became part of the Sono filter social network. Our workshop (December 29, 2012) revealed that MSUK never acknowledged suggestions of local governmental agencies with regard to filter distribution to villagers, partly because elected representatives of local government often tried to influence the distribution of filters politically. As a result of this poor interaction and lack of trust between MSUK and governmental agencies, diverging perceptions on the number of functional filters developed. MSUK claimed that 1400 out of 2000 filters disseminated in Mokarimpur union of Kushtia district since 2005 remained functional after seven years, whereas DPHE and local governmental agencies estimated this to be fewer than 100 filters.

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[42] E.g. Bangladesh Rural Advancement Committee (BRAC), Impact foundation Bangladesh, Village Education Resource Center (VERC), MSUK, Dipshikha, Dipsetu, Care Bangladesh, ADAMS, Nijera Kori, Jagoroni Chakro Foundation, SSF, LAFAS, Rotary Club, DPHE-UNICEF, NGO Forum for Public Health, DESCO Rajshahi, Rupantor and World vision etc.

[43] MSUK exported the composite iron matrix (CIM) to Pakistan in 2011 and under a licensing agreement a NGO in Nepal started manufacturing the filter in 2008. The two buyers confirmed that a total number of 2300 filters were imported from Bangladesh until 2014.

In disseminating the filters, an ad-hoc small network of households, user groups and community service providers was established by the NGOs (as institutional buyers) to monitor the users. Our interviews with users and the workshop (December 29, 2012) revealed, however, that the user monitoring system collapsed when the projects were phased out (given that a project was usually designed to disseminate a certain number of filters for a limited period of 2-3 years). Besides, due to lack of availability of filters during the post-project period, users faced challenges in receiving a new filter, replacing the old one, or obtaining spare parts. This disconnection between users and implementing NGOs (and with MSUK), caused by the ending of the projects, converted users either into non-users or one-time users. As such, the users did not actively participate in niche formation, except as receivers of the technology through projects.

In sum, the initial research and development network was small but deep and contributed to niche formation activities. The manufacturing network, however, was also small but not deep, and neither was the procurement network (which was almost entirely project-based). Therefore, the lack of depth in the manufacturing, monitoring and procurement networks, guided by fund-driven and time-bound projects, contributed especially to stagnation in niche formation.

4.5.2. Shaping and convergence of expectations

While many NGOs working on arsenic mitigation disseminated several technologies, MSUK was producing and disseminating only the Sono filter. A policy maker from DPHE (25 July, 2013) stated that “regardless of what people expect and prefer, implementing agencies deploy the technologies they want or are suggested by donors, as most projects are donor-funded. Basically, projects enforce users to use a particular technology without keeping in mind what users want” (see also Kundu et al., 2016a). Similarly, three focus group sessions revealed that users urgently needed an arsenic mitigation technology and MSUK provided them with the Sono filter without offering any alternatives. MSUK’s expectation that the Sono filter would help to mitigate the arsenic crisis initially converged with the expectation of governmental and donor agencies. For instance, DPHE and UNICEF were convinced of the usefulness of the Sono filter in arsenic mitigation at household level and disseminated 10,000 Sono filters through NGOs via arsenic removal technology projects between 2006 and 2008. A widely shared expectation that prevailed among policy actors was that various alternative technologies for safe drinking water sourcing (for instance, deep tube well) were not feasible everywhere. This was coupled with the expectation that the diffusion of the Sono filter would eventually increase in some areas for mitigating the arsenic crisis. These two interrelated expectations shaped their willingness to promote the Sono filter initially. Based on these expectations, policy actors devised specific policies and plans (such as the National Arsenic Mitigation Policy and Implementation Plan for Arsenic Mitigation), wherein the Sono filter was seen as an emergent and feasible solution for arsenic mitigation. But, in contrast to the Sono filter production network, implementing agencies (NGOs), governmental agencies and international donors expected that filter technologies, such as the Sono filter, would not be a long term sustainable option in rural settings. Similarly, after the abandonment of Sono filters after using them for approximately two years, users also realized that the Sono filter was not suitable as a long term mitigation technology. One user (December 23, 2012) stated that "...we now expect a technology that will provide us arsenic safe drinking water for many years without any disruption". This was the start of a divergence of expectations among these key actors in the network. The reasons for divergence included issues such as the short life span of the filter, or the need for regular monitoring, both of which would have required additional financial resources or sustained involvement of key actors.

Two additional aspects also contributed to such diverging expectations. The first was related to disposal of the arsenic-rich sludge produced by using the Sono Filter. Although the Sono filter met governmental environmental standards, there was still a lack of sufficient information with regard to effective processes and methods for arsenic-rich sludge disposal. Interviews with eleven implementing NGOs revealed that MSUK did not emphasize the importance of disposal of sludge, which eventually made the implementing NGOs and users reluctant to further promote the use of the filter. A second issue was lack of clear information about when a filter media had to be replaced. MSUK claimed that "...arsenic laden Composite Iron Matrix material is non-toxic. We buy back discharged filter material but frankly it is not more toxic than normal sand" (Hussam, 2009: 101). However, the users and implementing NGOs that we interviewed confirmed that no one took back filter media. Implementing agencies had no idea of where the users disposed the arsenic rich sludge. Additionally, a DPHE engineer (December 13, 2011) explained how difficult it would be for the implementing agencies (NGOs and DPHE) to monitor the timely replacement of filter media and to organize the disposal of sludge in post-project periods. Similarly, a UNICEF expert revealed (April 10, 2013) that "donors … have a choice, because removal technologies do not all have a good track record in terms of performance.... Hence … donors [can decide] to stop funding a running project that disseminates filters." In line with this, DPHE and international development agencies started to promote community-level non-filter technologies, such as deep tube wells. The absence of shared and converging expectations on safe filter media removal and timely replacement contributed to the withdrawal of NGO and governmental support for the Sono filter as important to mitigating the arsenic crisis.

A second issue was diverging economic expectations. In Bangladesh, all technologies disseminated under arsenic mitigation projects were highly subsidized, with usually 90-95% of the installation costs(in some cases, it was 100%) financed by implementing agencies through governmental or donor agency support. From the very beginning, MSUK did not receive governmental support to manufacture the filters, except for procurement order for a UNICEF supported project. Without such financial support, MSUK had to rely directly or indirectly on NGOs and donor agencies to obtain investments for manufacturing and dissemination of the Sono filter. Practically, MSUK could only start manufacturing when a procurement order was available. Lack of funded-projects and shifts in technological preference (from filter to non-filter based options) led to a discontinuation in the procurement of the Sono filter by institutional buyers after 2011. Only four NGOs (VERC, Impact Foundation Bangladesh, Dipshikha and Rupantor) procured 200, 1500, 60 and 210 filters during 2011-2014. MSUK was also unable to obtain significant financial support from crucial NGOs, such as Asia Arsenic Network, Water Aid Bangladesh, NGO Forum for Public Health and Bangladesh Rural Advancement Committee (BRAC), which had large water and sanitation programmes in rural areas. The economic expectation of the Sono filter innovators/producers to receive a total amount of US$750 million to meet the required manufacturing cost of 15 million Sono filters diverged from the expectations of the government (DPHE)[44], major NGOs and the international development community that filter technologies in general were mainly a short term solution in Bangladesh. The only alternative then for MSUK was to rely on a market strategy.

Users expected to receive a fully subsidized Sono filter from the implementing agencies, as a non-subsidized filter was not affordable for them. This expectation was shared by implementing agencies, including MSUK, and donors within project periods. Even after a project stopped, users expected a pivotal role of NGOs and the government in obtaining a highly subsidized filter. Once donors and implementing agencies withdrew support, filter users no longer articulated demand for the Sono filter. We found a large consensus among hybrid actors (government, donors and NGOs) that, given its price and challenges in usability, users would not buy the Sono filter. MSUK developed neither a strategy for a commercial market for Sono filter as an arsenic mitigation technology, nor a strategy to create a niche market (with a protected space from the mainstream market).It also did not convince existing industrial actors to promote the Sono filter instead of (or in addition to) tube well technology. The MSUK chairman (December 05, 2014) revealed that MSUK planned to allow others to produce the Sono filter by 2020, but we found no other organization planning to be involved in Sono filter production. MSUK also failed to launch outlets and service centres elsewhere in the country, except for a small display point in Dhaka[45], hindering users and implementing agencies from getting easy access to repair and spare parts.

Hence, with a clear Implementation Plan for Arsenic Mitigation indicating that MSUK could expect nothing from policy and government, MSUK's expectation for filter production and dissemination depended too much on donors and implementing agencies, and not at all on market actors. But the implementing agencies and donors perceived a number of socio-technical problems with the Sono filter (such as high cost, absence of longevity, poor availability of filter media and spare parts, unfriendly usability, shortcomings in monitoring of the filter, and absence of communications between MSUK and institutional buyers), resulting in diverging expectations regarding its viability between them and the network developing and producing the filter.

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[44] The amount is equivalent to 25 percent of the annual development budget of Bangladesh (Barkat & Hussam, 2008).

[45] Human Development Resource Centre, a Dhaka based non-governmental research organization, headed by inventor’s brother.

4.5.3. Learning process

Learning processes are expected to be a contributing factor to niche formation. The first order learning refers to the solution of techno-economic problems. Six areas of first order learning evolved from field experiences with production and dissemination of the Sono filter. First, modification in the design of the Sono 3-Kolshi model to the Sono two-bucket filter increased the durability of the filter up to 5 years and offered better convenience for users. However, the MSUK did not replace the poor quality (fragile) bucket with a higher quality bucket, given that this would increase the cost of the filter. Second, MSUK learned how to manufacture the filter with locally available materials and developed an essential network with local suppliers. This helped to obtain international recognition for a low cost, intermediate/appropriate technology. Thirdly, institutional buyers realized the importance of receiving training to help Sono filter users to install and maintain the filter system, so as to be functional in rural settings. Fourth, learning about the importance of careful transporting of the filter prevented unnecessary damage to them. Fifth, as the filter was not affordable for rural users, MSUK and other NGOs learned to arrange direct or indirect foreign funding to disseminate the filter more widely. Finally, regular updating of involved network actors on the Sono filter through a website seemed useful in the initial stage, although many website sections were never fully developed and were not kept updated. Such learning processes are characterized here as first order learning, because they aimed for technological and economic solutions and did not entail a fundamental change of the values and goals underlying activities relating to the production and dissemination of the Sono filter.

In investigating whether second order learning also took place, in ensuring the success of niche formation, the focus in this analysis was mainly on learning processes of two key actors: users and MSUK. First and foremost, learning about the importance and value of safe drinking water never materialized around the Sono filter. Focus group sessions revealed that users were generally not willing to spend money on securing safe drinking water. Again, the apparent failure of implementing agencies to alert arsenic victims about the health risks of drinking arsenic contaminated water did not contribute to reflexive learning about the importance of buying the Sono filter. As one user stated (December 13, 2012), “we used filter only after getting it from the NGO…[but] it is not [a] long term solution… NGOs will not provide free of cost filter again so we need a strategy to obtain a new filter”. Users thus focused more on getting a free filter, rather than exhibiting reflexive learning about the importance of drinking arsenic free water, and thereby adjust earlier expectations of not having to spend money on acquiring the Sono filter. Our interviews with ADAMS and Dipshikha (28 October, 2013) further highlighted that the users saw themselves as beneficiaries, rather than as consumers or participants in this process. MSUK did not learn how to involve users as active participants in the innovation processes, so that users could contribute to niche formation. Nor did users express a willingness to redefine their roles in mitigating the arsenic crisis, by actively participating in arsenic removal project developments or through buying a filter.

Furthermore, the usage of filters introduced new water use practices requiring adaptations from users: distinguishing water qualities for different use practices, planning clean water production, cleaning filters, changing of filter media, replacing the filter after lifespan. These changes in water use practices and the closer involvement in safe water provisioning (for instance by spending (more) money) are second-order learning processes, involving fundamental changes in values aligned with drinking water and rural livelihoods. Yet such fundamental shifts either did not occur. Users also never engaged in second order learning about the principles and technical design of the Sono filter, missing opportunities to reduce skepticism and increase understanding and self-reliance regarding repair. For instance, many users in the focus group sessions indicated that "we do not know how sands, bricks and charcoal can remove arsenic?" Despite the efforts of innovators to disclose technical knowledge about the filter, the debates over disposal of arsenic-laden waste also remained prevalent (e.g., Adel & Hossain, 2008; Ahmed & Ravenscroft, 2009). Finally, users were also not empowered to negotiate with state agencies and NGOs to ensure filter promotion, keeping them fully dependent on implementing agencies.

At the same time, MSUK also failed to get engaged in second order learning. No monitoring, evaluation and service/repair infrastructure was developed, to ensure continuous supply of the filter (and spare-parts, such as filter media) throughout the country and to ensure continuous dialogue with users and implementing agencies on experiences and failures. MSUK also did not learn how to develop a specialized niche market for arsenic mitigation with users and implementing agencies as regular market buyers of the filter. Instead, MSUK was preoccupied with short term exploitation of its patent advantage, keeping a monopoly and thus restricting widespread dissemination of filter and its services. MSUK and other NGOs developed no strategy to empower vulnerable people at risk to lobby the government and donors for continual supply of the filter, nor did MSUK involve implementing NGOs in clarifying to governmental agencies and international development partners the importance of safe drinking water and of Sono filter niche formation, and thus building trust. Consequently, elected representatives of local government institutions (LGIs) were not interested in getting involved in promoting the Sono filter, as arsenic mitigation was not a top priority for them. They claimed that MSUK produced and disseminated the filter because it earned money from foreign donors. This lack of trust between MSUK and LGIs also demotivated the latter actor from being involved in Sono filter niche formation.

Hence, while first order learning initially supported niche formation, the lack of second order learning stagnated further niche development.

4.6. Discussion and conclusion

This paper commenced with the assumption that despite its ability to remove arsenic from drinking water supplies in rural Bangladesh, the Sono filter's initial take-off stagnated after some years. Three dimensions of niche formation were explored in explaining this stagnation: social network composition, shaping and convergence of expectations, and learning processes.

The Sono filter network for research and development activities was small but deep and hence effective in initial conceptualization of the technology. However, the network for manufacturing, monitoring and procurement was neither broad nor deep, and did not enable MSUK to mobilize financial resources beyond institutional procurements. Again, there was no marketing network to promote and disseminate Sono filter. In addition, due to lack of interaction, many core hybrid actors (such as governmental agencies, donors, and NGOs) were no longer part of this network in the post-project period. Therefore, the social network composition for niche formation was strongly determined by fund-driven projects (and procurement orders). This can be explained by the low levels of interaction and coalition building between MSUK and other actors during the projects, which restricted the development of an effective network that could continue after the projects ended (see also Paul, 2004; Sekar & Randhir, 2009; Khan & Yang, 2014). The overall failure of MSUK to develop a more institutionalized partnership with international donors, DPHE, other NGOs, users and media deterred the process of continued niche formation. Active network participation of users and NGOs would have made the niche formation more successful, with their roles moving beyond beneficiaries and institutional buyers, respectively.

Furthermore, the findings show that the critical evaluation of the social, economic, environmental and technical performance of the Sono filter by policy actors, international donors, and experts resulted in diverging expectations over whether it could contribute significantly to solving the arsenic crisis. Such diverging expectations (between producers and disseminators of the technology) resulted from issues such as its high cost, short life span, troublesome maintenance, lack of monitoring, unwillingness of users to pay, and lack of agreement on arsenic sludge removal etc. This non-convergence of expectations between MSUK and hybrid actors (donors, governmental agencies, NGOs and users) hampered niche formation, as project funding became increasingly restricted, priority of mitigating arsenic crisis has been shifted and no market strategy was available (on this point, see also Milton et al., 2012; Adams, 2013; Khan & Yang, 2014). In addition, the long-term preference of key policy actors for community-level non-filter technologies (such as the deep tube well) also influenced the mind-set of NGOs, donors and the government, hampering further the success of Sono filter niche formation.

With regard to learning processes, the analysis reveals that first order learning in six areas (design, manufacture, training, transporting, funding and informing) contributed to the initial success of niche formation. However, a lack of second order learning by users of the Sono filter and MSUK prevented further niche stabilization, and resulted in stagnation rather than further uptake of this technology. Lack of second order learning resulted in continued strong dependence on highly subsidized technology dissemination, with declining participation from users, donors and other NGOs in the core network. Second order learning to transform users from beneficiaries of the projects to potential buyers of filters, and other NGOs from competitors to collaborators, could have contributed to continued successful niche formation.

These findings also provide insight into the interactions between technological niches, such as those for the Sono filter, and the existing socio-technical safe drinking water regime in Bangladesh. Confronted with the arsenic crisis, policy actors were evolving a clear preference for community level, non-filter technologies, instead of household filters, in the same period of time as the Sono filter was being developed and deployed. For instance, the deep tube well– a close alternative to shallow hand pump tube well – is now dominant in arsenic mitigation in Bangladesh (Ravenscroft et al., 2014; see also Kundu et al., 2016a). As the analysis has shown, a variety of factors, including lack of support from policy actors and absence of a market, and the need to change existing user practices, hindered successful Sono filter niche formation. As such, it could not compete with the evolving preferences for non-filter based technologies (especially deep tube well),which had been part of the socio-technical drinking water regime even before the arsenic crisis hit. Thus, despite initially successful niche formation, the introduction and dissemination of the Sono filter could not significantly alter the socio-technological safe drinking water regime in Bangladesh following the arsenic crisis.

In concluding, the utility of the conceptual lens used in this analysis can be briefly addressed, centered on the strategic niche management (SNM) perspective to explain the Sono filter's initially successful niche formation, but subsequent stagnation. As the analysis demonstrates, an SNM perspective has proved useful in explaining this stagnation, and the failure of the Sono filter to become a key part of the current safe drinking water socio-technical regime. Beyond the problems associated with these three dimensions of niche formation, this paper clearly shows that the overwhelming dependency on fund-driven projects may not always be helpful to make niche formation successful in the context of the developing world.

This notwithstanding, the analysis also suggests that the Sono filter can have a (limited but important) role to play in mitigating the arsenic crisis in Bangladesh, as there are no other competitive niche filter technologies currently available at household scale, and there will always be locations where deep tube well technology is not feasible to deploy. For it to play such a role, however, key actors in the network need to prioritize second order learning, in order to advance filter production, marketing, and dissemination, and to develop a vibrant, inclusive and reflexive network, wherein expectations (especially of MSUK, users, and NGOs) are able to converge. This is particularly important in light of the predominantly donor funded and time-bound projects within which niche innovations are nurtured in a developing country context.

Chapter 5

Experimenting with a novel technology for provision of safe drinking water in rural Bangladesh: The case of sub-surface arsenic removal (SAR)

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Abstract

Subsurface Arsenic Removal (SAR) is a technique used for in-situ removal of naturally occurring arsenic in groundwater. This new technology was deployed recently on an experimental basis in two sites in rural Bangladesh, to address the pressing problem of rural drinking water supplies contaminated by arsenic. This article assesses whether and to what extent these first field experiments with SAR can be conceptualized as "socio-technical experiments" designed to incubate and improve radical technological innovations by serving as 'living lab", "window" and/or "agent of change". As per writings in transition theory, an experiment functions as a living lab if it permits testing, learning and improving upon a technological innovation. It functions as a window if it is able to facilitate communication and conversation by raising actors' interest and enrolling new actors. It functions as an agent of change if it can successfully stimulate changes in potential users' practices and behaviours. Through studying two SAR experiments, this article finds that this novel technology served as a living lab and window, but not (yet) as agent of change, partly because integrating social considerations (such as community buy-in, appropriate site selection and post-installation support) into SAR prototype design during field experimentation proved very difficult. A key obstacle was that the technical efficacy of the technology remained a primary concern during experimentation, and it was unsafe to make water deriving from experimental SAR units available to users. The technology thus remained an abstract idea and provided unable to stimulate behavioural changes amongst users. We conclude that there is a need to identify conditions under which real world experiments can serve as agents of change to facilitate sustainable uptake of arsenic safe technologies in rural developing country contexts.

5.1. Introduction

Naturally occurring arsenic contamination of groundwater in shallow aquifers is a health and development disaster that severely limits the access to safe drinking water for millions of people living in rural areas of Bangladesh (Ahmed et al., 2006; Chakraborti et al., 2010; Hossain & Inauen, 2014). The arsenic contamination of groundwater poses challenges to the sustainability of safe drinking water supplies in the country. As a result, after the first detection of naturally occurring arsenic in the ground water in 1993, the provision of safe drinking water coverage for rural populations dropped from 97% to 72% by 2000 (Smith et al., 2000; Johnston et al., 2010; Inauen et al., 2013). A wide range of solutions have been proposed and tested since, focusing either on filtering out arsenic from pumped up groundwater or providing alternative sources of safe drinking water. All of these arsenic mitigation and safe drinking water options face various technological, economic and/or social challenges and limitations (see Hoque et al., 2006; Shafiquzzaman et al., 2009; Johnston et al., 2010; Milton et al., 2012; Kundu et al., 2016a). Furthermore, no single solution is feasible for all arsenic affected areas (GoB, 2004a, 2004b), given diversity of geo-hydrological and social conditions. Therefore, an interdisciplinary research initiative was launched in 2010 to investigate a new, experimental innovation in the form of “sub-surface arsenic removal” (SAR) technology, to explore its promise in providing arsenic safe drinking water in rural Bangladesh. SAR technology is linked to the existing infrastructure of a shallow hand pump tube well, which is relied upon by the vast majority of Bangladesh’s rural population as the dominant source of their drinking water. It aims to retain arsenic in the subsurface (Rott et al., 2002; Sarkar & Rahman, 2001; van Halem, 2010), but without relying on chemical-based filter media and without grappling with the challenge of safe disposal of arsenic-rich sludge.

SAR operation involves the following consecutive steps: extraction of anoxic groundwater from the aquifer with arsenic and iron, aeration of the extracted water in a tank, re-injection of the aerated water into the same aquifer and lastly, extraction of larger volume of water with lower arsenic concentrations (van Halem, 2010; Rahman et al., 2014; Freitas et al., 2014). Several research and policy documents (GoB, 2011; Ravenscroft et al., 2009) strongly endorsed the desirability of researching and developing SAR, the idea of which builds on the extensive practical experience with (similarly designed) sub-surface iron and manganese removal technologies in Germany and Netherlands (van Beek, 1985; Appelo et al., 1999; Mettler, 2002; van Halem et al., 2010).

This paper considers SAR technology as a radical innovation in the Bangladeshi context. Even though it relies on the existing infrastructure of a shallow tube well, it does require adoption of new water use practices and does not fit directly into the existing socio-technical safe drinking water system in rural Bangladesh. This technology was incubated in the laboratory and then deployed for purposes of experimentation in rural Bangladesh by a research team from the Netherlands and Bangladesh (van Halem, 2010; Rahman et al., 2014; Freitas et al., 2014). This paper conceptualizes this as “real world experiments” (Gross & Hoffmann-Riem, 2005), and uses a transition theory lens to understand the transformative potential of such experimentation. In particular, the paper uses the concept of ‘socio-technical experiments’, originating within transition theory, as a framework to understand the emergence and dynamics of radical innovations (Rip & Kemp, 1998; Ceschin, 2014). Our point of departure is that socio-technical experiments are likely to play a crucial role in meeting the broader challenges of providing safe drinking water, for three reasons. First, they permit testing and improving of technological innovations; second, they can enhance the process of technological niche development (with the understanding that a technological niche is a protected space where radical innovations emerge and develop); and third, such experiments can, as Ceschin (2014:3) puts it,“ stimulate changes in the broader socio-technical context in order to create favourable conditions for scaling-up of an innovation”.

Existing social science research relating to arsenic contamination has largely neglected the study of real world experiments for radical innovation. At the same time, available research in the domain of arsenic removal technologies for safe drinking water shows limited success in application and scaling-up of radical innovations in Bangladesh (see Ahmed et al., 2006; DPHE & JICA, 2009; Inauen et al., 2013; Ravenscroft et al., 2014; Hossain & Inauen, 2014; Kundu et al., 2016c). Therefore, our aim here to examine whether and to what extent SAR has functioned as a socio-technical experiment in rural Bangladesh, and the consequences for niche development and scaling-up of this innovation. In doing so, we aim to contribute to the literature within transition theory on socio-technical experimentation and niche formation, particularly in the context of developing countries.

We proceed as follows: Sections 2 and 3 present our conceptual framework and methodology. Section 4 discusses two real world experiments relating to SAR undertaken in rural Bangladesh. Section 5 presents our findings regarding the functions that real world experiments with SAR are fulfilling. Section 6 contains a discussion and conclusion.

5.2. Conceptualizing a socio-technical experiment

Transition theory puts much emphasis on radical innovation, considering it a driving force in stimulating societal change (see Geels, 2002; Schot & Geels, 2008). In particular, the widely-discussed multi-level perspective (MLP) in transition theory explains how major socio-technical change takes place as a result of dynamic interactions among three functional levels (Geels, 2002; Schot & Geels, 2008). These three levels include, first, the (*macro*) landscape level, which consists of rather inert contextual conditions against which specific socio-technical changes occur (Geels, 2002). The second (*meso*) level consists of a sociotechnical regime or a “stable configuration of culture, practices and institutions related to a specific domain (e.g., safe drinking water) (Rip & Kemp, 1998: 340). The final level is the *micro* level, which refers to protected spaces wherein radical innovations emerge and receive support (Kemp et al., 1998). These radical micro-level innovations can over time either become included within, or else serve to challenge, an existing socio-technical regime. Hence technological niches can perform the function of being protected spaces for radical innovation, wherein real world experiments can take place (Geels, 2002; Hegger, 2007).

In this connection, the concept of 'socio-technical experiment' has emerged to analyse how to incubate and improve radical innovations and contribute to their social embedding (Rip & Kemp, 1998; see in particular, Ceschin, 2014). A key characteristic of such experiments is that they are not simple tests in a laboratory but are implemented in real life settings. A broad variety of actors are involved. Initially, these experiments are implemented in "niche" spaces protected from the mainstream selection environment. Yet even though these experiments take place at a small scale, they have the potential to trigger changes at wider scale.

As a conceptual framework for our analysis, we apply Ceschin's (2014) concept of 'socio-technical experiments' to the case of Bangladesh. Although socio-technical experiments can be seen as a management tool to enhance the process of transitioning to sustainable radical innovations, we view the notion here as an analytical tool. Ceschin usefully conceptualizes 'socio-technical experiments' as consisting of three successive phases: incubation, experimentation, and niche development and scaling-up (see Figure 1). According to Ceschin, incubation refers to necessary arrangements needed to start the socio-technical experimentation, whereas experimentation refers to implementing processes designed to support societal embedding. Lastly, niche development refers to transforming experiments into a fully operative service with protection and scaling-up emphasizes removing the protection (Ceschin, 2014).

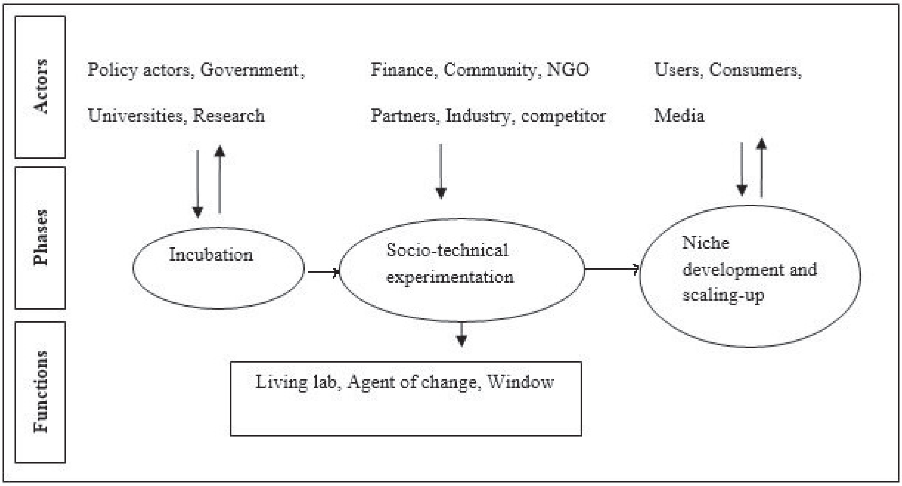

Figure 5.1: Conceptualizing three phases and functions of socio-technical experiment (adapted from Ceschin, 2014)

We focus our analysis in this article on the first two phases of a socio-technical experiment (incubation and experimentation), given our explicit interest in analysing the conditions necessary to move to the stage of niche development. In particular, our interest is to explore whether socio-technical experimentation can enhance uptake of radical innovations through fulfilling three key functions: Living Lab, *Window and Agent of Change*. According to Ceschin (2014), a socio-technical experiment acts as a *Living Lab* when "local shifts and barriers in culture (way of thinking, values, reference framework, etc.), practices (habits, ways of doing things, etc.) and institutions (norms, rules, etc.)" are identified by testing, learning and improving the innovation (Ceschin, 2014:4). Such experiments fulfil the second function of serving as a *Window* if experiments are utilized as "communication and conversation tools to build support and legitimacy by raising actors' interest and enrolling new actors" (Ceschin, 2014:14). Finally, experiments function as an *Agent of change* when actors' practices and behaviours are altered to make the radical innovation successful. Our aim here is to analyse whether, and to what extent, the real world field experiments with SAR technology fulfilled these three functions in rural Bangladesh, and hence whether these can be characterized as successful socio-technical experiments, paving the way to future niche development and scaling up. We turn next to how we operationalize these three functions in undertaking our analysis.

5.3. Methods and approaches

In order to understand whether and to what extent real world experiments with SAR can be conceptualized as a socio-technical experiment that fulfils the three key functions outlined above, a case study methodology was followed, using mainly qualitative data collection methods. Case study methodology is appropriate when research deals with an exploratory question and studies a phenomenon within its real-world context (Yin, 1998). We conceptualize the two real-world experiments with SAR technology in our article as a single case to test the application of our conceptual framework outlining functions of sociotechnical experimentation.

For the real world experiments, we selected two sites to test SAR prototype technology in the field. Two villages (Payob and Bangala) were selected, in the first instance, on the basis of crucial water quality parameters (relating to, for example, the concentration of iron, silicate, bicarbonate, phosphate and manganese along with arsenic in shallow tube well drinking water). The first experiment was carried out in Payob, a village in the Muradnagar Upazila (sub-district) of Comilla district, about 100 kilometres southeast of Dhaka, the capital city of Bangladesh. More than 90% of the shallow hand pump tube wells in Payob contain levels of arsenic concentration three or four times higher than the Bangladesh guideline value of 50 µg/L (DPHE, Muradnagar office, 2011). The second experiment was implemented in Bangala, a village in the Singair Upazila of Manikganj district, about 40 kilometres southeast from Dhaka, where 93% of the shallow hand pump tube wells contain levels of arsenic concentration above the Bangladesh guideline value (DPHE, Singair office, 2014).

With regard to the broader context within which such experimentation took place, it was also important to assess alternative arsenic mitigation options already deployed in these two sites when considering site selection. Crucially, the most preferred alternative safe drinking water option to contaminated shallow tube wells, the deep tube well (see Kundu et al, 2016b), was not feasible to install in either village, due to the presence of highly saline water in the deep aquifers and hard gravel layers at 150 metres depth in Payob and Bangala, respectively (DPHE, Muradnagar and Singair office, 2011 and 2014). As a result, several other arsenic mitigation technologies, including pond sand filter, rain water harvesting units and improved dug wells, had been installed in both villages at various points in time, all of which were abandoned within one year of their installation (as revealed during a consultation meeting with villagers). As a consequence, both villages had practically no functioning arsenic mitigation technology available, other than a few safe shallow hand pump tube wells. These had been tested before 2005, however, and it remained uncertain whether they could still be characterized as safe.

Table 5.1: SAR real-world experiments: study areas, methods and respondents

Real world Experiments	**Study area/ time duration of experiment**	**Methods of data collection**	**Respondents**
1.Experiment A with SAR (no users and potential users involved)	Payob village (November 2011- October 2013)	Consultation meeting	Three meetings, with a total of 55 villagers and community representatives
		In-depth interviews	Nine interviews with school authorities, scientists, DPHE engineers, and personnel at hardware shops
		Focus group discussions	Six focus group discussions (three each with male and female members) with a total of 43 people
2.Experiment B with SAR (users involved)	Bangala village (January 2014- December 2014)	Questionnaire survey	Respondent set consisted of 134 villagers
		Consultation meetings	Three meetings, with a total of 43 community representatives
		In-depth interviews	21 interviews with users and management committee members, three with scientists, one with DPHE engineer, two with hardware shops and two with local government institutions

During two real world experiments with SAR at these two field sites, data were collected between November 2011 and December 2014 through in-depth interviews, consultation meetings, focus group discussions, observation and informal discussions (see Table 5.1 and below). Data collection activities centred on generating information relevant to assessing the fulfilment of the three key functions of socio-technical experiments: whether these served as a *Living lab, Window* and *Agent of change.* Each of the three functions was elaborated through, in the first instance, relying on the indicators and variables developed by Ceschin (2014). To generate data on these, we developed detailed checklists to operationalize and assess the three functions in the course of our fieldwork (see Table 5.2). In doing so, we drew on the the indicators and variables developed by Ceschin for each of the three functions, which he further validated by conducting a case study in a developed country context. We have contextualized these indicators and variables for a developing country. The checklists and guidelines were validated through a pre-test to ensure their applicability for studying sociotechnical experimentation with SAR technology in rural areas of Bangladesh. A set of sample questions that we drew on to obtain data is included here as Annex 1.

We started data collection by identifying relevant actors to solicit information from, including community representatives, potential users of experimental SAR technology, non-users, technicians, personnel at hardware shops, school authorities, and representatives of the Department of Public Health Engineering (DPHE) and members of local sub-national governmental institutions. A total of six consultation meetings, 30 in-depth interviews, six focus group discussions and questionnaire surveys were conducted targeting these groups (see Table 5.1).

Participants for consultation meetings were selected from community representatives, including community and religious leaders, elected female and male representatives of local government institutions, teachers, household heads and elderly people involved in decision making. In addition, the respondents for in-depth interviews were actively involved in one of the two experiments, and included school staffs (first experiment was installed at the Payob Secondary High School premise), scientists, (potential) users, water management committee members, engineers, personnel from hardware shops and local government authorities (see Table 5.1). Additionally, following a list of households provided by the Department of Public Health Engineering (DPHE), 134 respondents (one male or female from each household) were selected to participate in the survey. Additional information was generated through observation and informal discussions.

Table 5.2: Operationalization of the three functions of socio-technical experiments: indicators and checklists

Three functions	**Indicators and variables**	**Checklists/ Guidelines**
Living Lab	Identify local shifts and barriers in culture (way of thinking, values, reference framework, etc.)	Beliefs and perceptions on: reference technology (shallow tube well) and its attributes, possible solutions to arsenic contamination; appropriate design and functioning of safe drinking water technologies; characteristics of desirable technologies; attributes of safe drinking water: i.e. freshness and purity; awareness and priority assigned to arsenic crisis, etc.
	Identify local shifts and barriers in practices (habits, ways of doing things, etc.)	Habits and practices relating to: water usage (both existing drinking water options and experimental SAR); issues relating to location of water sources; ownership patterns; community interactions; quantity of water used; times of water collection; security of the women while collecting water; diversity of purposes for which water was used from same or different sources; SAR; investments in safe drinking water options, etc.
	Identify local shifts and barriers in institutions (norms, rules, etc.)	Existing institutional arrangements and formal and informal rules and norms relating to: means of community interactions, including issues of social stratification and inter-and intra-religious differences; complexity of organizing, operating and functioning of village committees and associated decision making procedures; funding arrangements, including methods of collecting payments for electricity bills: arrangements for payment and repairs of existing water sources; formal and informal institutional arrangements for mediation of ownership conflicts.
Window	Utilization of experiment as communication and conversation tools (raising actors' interest, enrolling new actors)	Did the experiment serve to identify new and critical issues; immediate and long term benefits; characteristics of context-specific appropriate solutions; suggestions for potential improvement of the technological prototype; enhanced prospects for regular meetings and consultations; address issues of distance and service coverage; willingness to participate; and success in raising users' interest through providing information, feedback on service, design, network etc.
		Effects and success of research team strategies to inform villagers, involve new users, engaging potential users and stakeholders, monitoring formal and informal meetings etc.
Agent of change	Actors' practices and behaviours are altered to make the radical innovation successful (actors' behaviours and practices)	Specific shifts in practices and behaviours relating to: motivation to participate; shift from household-scale to community scale in accessing water for daily needs; water use and collection patterns; broadening diversity of uses for safe drinking water, including for cooking (not only drinking);adjudicating ownership conflicts; institutional arrangements to address (lack of) cooperation and coordination, and intra- and inter-religious conflicts and social stratification; diversifying sources of water for multiples uses; etc.

5.4. The real world experiments with SAR

This section contains the analysis of the first two phases of the SAR socio-technical experiment (incubation and experimentation).

5.4.1. Incubation

The incubation phase of the SAR experiment began with formulating a research proposal by a team of Dutch and Bangladeshi researchers in 2009, which evolved from earlier SAR-related research in Bangladesh (see van Halem et al., 2010). This earlier research in Bangladesh had attracted the interest of governmental (DPHE) and non-governmental (UNICEF) organisations, and these local stakeholders encouraged the Dutch team of researchers to continue with the research. A SAR workshop in Dhaka concluded that, even if sub-surface arsenic removal efficiency lagged behind that of sub-surface iron removal (a more well-established technique at the time), a technology that could (eventually) effectively retain arsenic in the sub-surface would be extremely valuable for rural areas in Bangladesh and hence worth investigating. Since SAR technology does not require much additional hardware, nor consumables like adsorption media, it was considered particularly promising to explore in the context of a comprehensive arsenic mitigation strategy in Bangladesh.

Consequently, a research group consisting of Bangladeshi and Dutch staff and PhDs from four disciplines (hydro-geology, drinking water engineering, microbiology and sociology) developed a partnership with several government and non-government agencies. It was the explicit aim of this research group to experimentally develop SAR technology as an arsenic mitigation solution, simultaneously from a technical and social perspective in the diverse geo-hydrological settings of rural Bangladesh. Once the project proposal was granted, researchers conducted exploratory column and batch experiments in laboratories to understand the optimal hydro-chemical conditions for designing SAR technology. During the experiments, members of the research team coordinated the activities of various technical (local technicians, hardware shops, DPHE engineers, etc.) and social actors (community representatives, households, local organizations, etc.). After designing an implementation plan, the research team established necessary arrangements to carry out experiments in the field.

5.4.2. Socio-technical experimentation with SAR

After the incubation phase, two real world experiments were conducted in the field, which we analyse below as experiments A and B.

A. During the first experiment, the research team designed a working prototype[46] of SAR technology (see Figure 5.2) with the aim to make it attractive to potential users and investors by

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[46] A prototype is an initial design of a product that is real, tangible and workable and can provide indications for improvement of the final product (http://fortune.com/2012/05/07/6-reasons-why-working-prototypes-attract-investors/)

determining the best materials to assure desired performance and durability. The prototype of SAR consisted of: a tube well structure, large plastic tank, plastic pipes, electrical pump, disk aerators, valves, flow meters and air compressor. Prior to installation, researchers tested water samples with field test kits and collected groundwater samples based on test kit results for further analyses in the laboratory. The collected groundwater samples were examined in the laboratory to understand whether the concentration of arsenic and iron (and other elements such as silica, bicarbonate, phosphate, and manganese) comply with the optimal hydro-geochemical conditions determined in the laboratory for SAR experiments. It is worth mentioning that the availability of iron is a prerequisite for arsenic retention in the subsurface during SAR operation (Rahman et al., 2014).

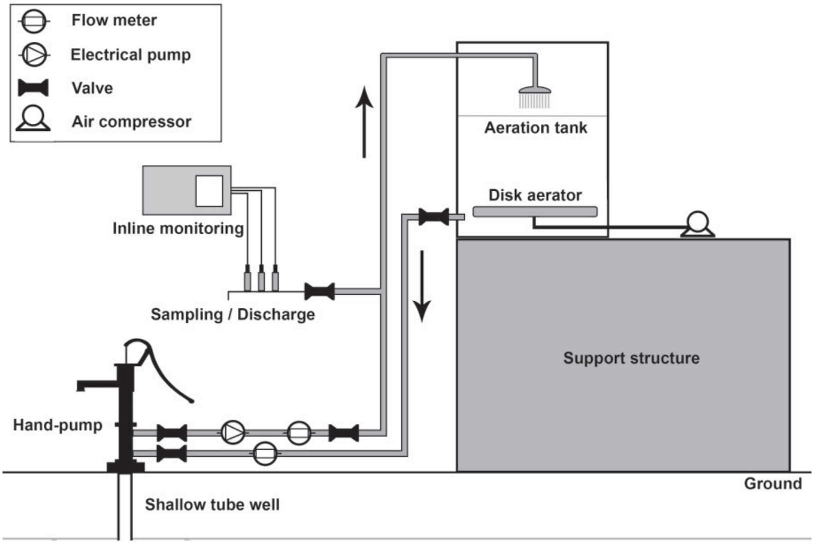

Figure 5.2: Prototype of Sub-surface Arsenic Removal Technology (Freitas et al., 2014; Rahman et al., 2014)

The research team selected Payob Secondary High School as a location that matches water quality parameters for installing this prototype SAR unit. Equally important, the school authorities (the owners of the spot) and local community representatives gave consent to the research team to utilize the school as a temporary laboratory. As part of installing two SAR units at the school with a distance of 55 metres from each other, the research team drilled two new shallow tube wells (20.5 and 22.5 metres deep) by using the "sludger" method (BGS & DPHE, 2001). Flow meters were connected to the injection and extraction lines to measure volumes of injected and extracted water. The injection and extraction pipes were connected to an aeration tank. Two separate tanks with 1000 and 5000 litres of injection capacity respectively for two different SAR units were used. The tanks were placed on a rooftop and showerheads and disc aerators were placed in the aeration tanks. An inline monitoring system was also established. In order to extract ground water, two electrical suction pumps with a generator were used (for detailed discussion of the SAR prototype, see Rahman et al., 2014).

As noted in section 5.1, the operation of SAR involves three consecutive steps (van Halem, 2010).This first experiment A was designed to determine the impact of alternative operations on SAR performance (Rahman et al., 2014). In all cases with alternative operations, SAR effectively removed iron; however, more than five consecutive cycles (one day per cycle, 5 days in total) were required to produce 2000 litres of arsenic safe water after the injection of 1000 litres of contaminated water. In the context of ease of use, this condition can be considered burdensome for users, since they have to wait for a few days to get arsenic-free water. Due to ethical reasons, potential users were not allowed to drink treated water during SAR operation at Payob, as the arsenic removal process did not yield the WHO arsenic safe water guidelines value in the water eventually pumped up for use. Focus group discussions conducted during and after this experiment revealed that it could not benefit potential users directly, who were in immediate need of safe drinking water.

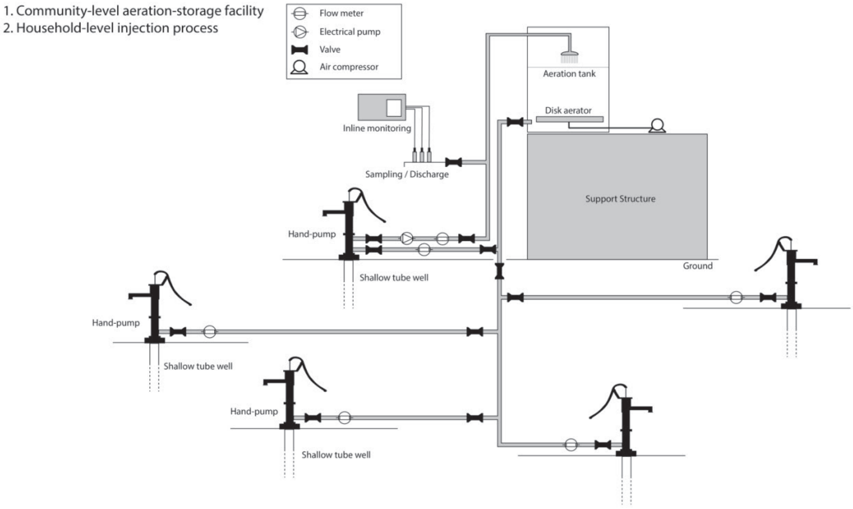

Figure 5.3: Experimental design of community level iron removal at subsurface and hand-pump arsenic removal for household scale of use (Freitas et al., 2014)

Based on lessons learned during this first experiment, the idea emerged within the research team to consider a redesign of the SAR prototype, so as to integrate subsurface *iron* (rather than arsenic) removal, with arsenic removal occurring *above* ground (see Figure 5.3). This was because the first experiment clearly showed effective retention of iron in the subsurface, with arsenic removal remaining less than optimal. The integration sought to combine community-level subsurface iron removal, with arsenic removal occurring above ground, while still linked to existing household-level shallow hand pump tube wells. The plan was to link the hand pump to an arsenic removal filter (above ground), in which filter media (e.g., Composite Iron Matrix or Granular Ferric Hydroxide) would be used. According to the implementation plan for this new prototype, household-level shallow hand pump tube wells were to be connected with one large tank to be deployed at the community-level for performing injection, aeration and abstraction of water. For this purpose, five households were responsible to store water in the tank through pumping the hand pumps at household-level (see Figure 5.3 above).

However, this modified design was never tested in the field, given that potential beneficiaries were not ready to implement a sub-surface technology that only removed iron. This became clear from a consultation meeting at Payob village with community representatives (Meeting # 3, 18 August, 2013), followed by six focus group discussions in the field (21-30 August, 2013), which revealed that the expectations of potential users and community representatives diverged from those designing the new prototype for the following reasons. First, it did not meet expectations of the potential users for a technology that delivered arsenic safe water, because installing SAR to retain (and thus remove) only iron from drinking water was not a priority for them. Second, visuals of the prototype appeared to be complex for potential users, particularly in terms of installation. Finally, managing the operation and maintenance of this combined household and community-level technology was perceived to be complex, time consuming and troublesome. Hence, divergence was found between expectations of the research team and user preferences. Consequently, the community-level sub-surface iron removal was not installed. The lessons learned from this aborted field experiment was that users' preferences regarding what constitutes a desirable technology are a key component in implementing real world experiments, which need to be taken into account in designing the experiment as well. This was an important outcome of experiment A, revealing that a technological innovation had to fulfil societal expectations and demand for it to be translated into a real world experiment.

B. The research team thus reverted to field-testing the first working prototype of SAR (which sought to also retain arsenic in the sub-surface, in addition to iron) in a second site in Bangladesh, Bangala village. The aim this time was to achieve a socio-technical breakthrough in arsenic retention in the sub-surface with an arsenic concentration of 100µg/L. This is the second sociotechnical experiment we analyse here (Experiment B). Two modifications to the technical design of the first prototype took place, based on lessons learned from the first experiment. First, two separate tanks (1000 litres capacity for aeration and 2000 litres capacity for distribution) were installed on a rooftop; and second, grid line electricity was used instead of a generator, once the users took responsibility for operating the SAR unit (see Figure 5.4).

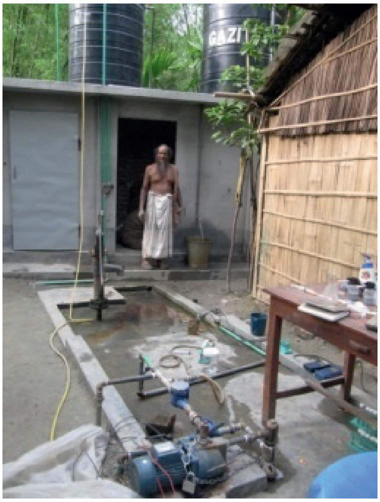

Figure 5.4: Caretaker in front of SAR unit experimentally deployed in Bangala village

In terms of financial requirements, with an estimated lifespan of 20 years for a SAR unit, the cost of installing SAR with an injection capacity of 1000 liters was US$ 925, whereas an additional US$ 130 per month was required for operation and maintenance costs including operator's salary, electricity and periodic repair (see also Rahman et al., 2014). In total, the cost for 1000 litres of treated drinking water was approximately US$2. Like the previous experiment A, the installation costs for Experiment B were financed by the research project, while potential users were responsible for operation and maintenance costs.

As part of the experiment, potential users who showed willingness to use the technology and contribute for monthly operation costs were trained. An operation and management committee was formed to ease the operation and maintenance of SAR and to accelerate community participation. Field test kit results showed that SAR's performance in removing arsenic had improved. For instance, the experimental SAR unit steadily removed arsenic to levels below Bangladesh guideline value of 50 µg/L in the first cycle, which required less than two days. Users started drinking water from the SAR unit as well.

However, six months after the installation of the SAR unit, the number of users dropped drastically. This happened due to several reasons: inconvenience relating to distance between beneficiary households and the location of the SAR unit; their unwillingness to continue spending for monthly operation costs; social conflicts with the caretaker; and reluctance of the management committee to mobilize users and organize meetings. Besides, due to lack of availability of lubricating oil, the air compressor connected with the disc aerators inside the tank became dysfunctional. As a result, the SAR unit could not remove arsenic as efficiently as before. Moreover, the SAR unit remained underused because only 200 litres of treated water was required to meet the daily demand of users, whereas the maximum production capacity of SAR was 2000 litres per cycle. The lessons learned from this experiment were that continuous mobilization of community and maintenance of technology were of crucial importance in expediting real world experiments.

5.5. Real world experiments: living lab, window and agent of change?

In analysing whether and to what extent the real world experiments of SAR described above served as a socio-technical experiment, this section examines the three functions that experiments need to fulfil: serving as a *Living lab*, *Window* and *Agent of change*.

5.5.1. Experiment as *Living Lab*

The first function that the real world experiments with SAR needed to fulfil was to serve as a *Living Lab*. Several actors including the research team, community representatives and (potential) users were involved in the two experiments. In this section, we consider whether and how these experiments helped to identify local barriers and shifts in culture (way of thinking, values, reference framework, etc.), practices (habits, ways of doing things, etc.) and institutions (norms, rules, etc.) in order to test, learn and improve the SAR innovation.

In the two experiments, users considered shallow hand pump tube well as a desirable technology that they were very familiar with and had used for several decades, and which was an integral part of rural culture. The shallow hand pump tube well became popular due to its ability to provide sufficient amounts of fresh drinking water and was appreciated for its simple design, easy operation and maintenance, and availability of spare-parts in local hardware shops. Male members of the households were able to fix minor technical problems. Besides, the low installation cost (US$ 100-130) with almost no operation cost enabled poor households to become the proud owners of a safe drinking water technology, which also bestowed upon them a higher social status.

While introducing the experimental SAR units in rural Bangladesh, even though they relied on the shallow tube well, three barriers were identified to their further consolidation and use: compared to the shallow hand pump tube well as a reference technology, SAR had: first, higher installation costs; second, spare-parts such as disk aerator and flow controller were not available in the local market; and third, local technicians (mesons) did not have adequate knowledge to install and repair SAR units unless they were briefed and trained. An interview with a SAR user (Interview #13, February 12, 2014) revealed that their existing technical skills were not adequate for operating and repairing SAR technology.

We found that introduction of SAR required some basic changes in existing practices related to safe drinking water in rural areas. For instance, users had a clear preference to continue to rely on household-level technology, such as their own individual shallow hand pump tube well. Practically, rural women –who were responsible for managing drinking water– preferred to access water from a shallow hand pump tube well to use for multiple purposes, such as drinking, cooking, bathing, cleaning and washing. Household-level technology provided enormous ease and convenience regarding distance, time and labour to rural women, in comparison with the community-level SAR units that required collection of water from a distant community spot.

Existing norms and institutions thus did not favour the widespread introduction of a community-level drinking water technology like SAR for two reasons. Firstly, households (117 out of 134) – irrespective of their socio-economic categories– were not willing to spend money for high installation costs, along with the monthly operation and maintenance costs for the provision of safe drinking water. Secondly, the existing social structure did not encourage people to form a community organization to maintain a community-level drinking water technology (94 out of 134). These findings contrast with the popular understanding that all people living in a village form a single community. Rather, a village is divided in several clusters on the basis of religion, occupation and social status. For instance, 17 members of the fishermen and dairy producers communities (Hindu by religion) considered collecting drinking water from a Muslim household a matter of disrespect (Meeting # 5, March 13, 2013). As one of our interviewees, echoing many others, stated "it is better for us to drink arsenic rich water than collecting water from a different community on a regular basis" (Interview # 27, October 12, 2014). Third, existing socio-religious norms militate against women and girls fetching water from a distant community location. For instance, many Muslim households (15 in number) stop collecting water from a household that belonged to *Baul* – a traditional mystic devotee in the Bengali culture (Interview #18,19,20, October 7-8, 2014). This finding reveals that selection of the location for deploying community-level technology is of immense importance.

We found that real world experiments with SAR nonetheless fulfilled the function of serving as *Living Labs,* as various relevant aspects of local culture, practices and institutions were revealed through the testing, learning from and (re-)designing of the prototype innovation. We turn next to considering whether these experiments also served the function of being a *Window*.

5.5.2. Experiment as *Window*

Real world experiments fulfil the function of *Window* if experiments are utilized as communication and conversation tools, in order to build support and legitimacy for them by raising actors' interest and enrolling new actors. At the beginning, dysfunctionalities associated with the existing arsenic mitigation options (for example, rain water harvesting in Payob and improved dug well in Bangala) discouraged villagers from getting involved with the SAR real world experiment (Meeting # 1, 3 June, 2012; Meeting # 3, 18 August, 2013; FGD # 3, 24 August, 2013). Several strategies to solicit community agreement and enthusiasm for the experiments were thus necessary, including consultation meetings and focus group sessions, where visual images and a working prototype of SAR were used as a communication and conversation tool. As a result, various actors, including school authorities, community representatives and potential users, allowed the research team to undertake the real world experiments, after they were convinced about the potential benefits of the experiment.

Involving diverse actors from the beginning was one of the ways in which Experiment B evolved. Experiment B involved many actors, including villagers (potential users), DPHE officials, local Union Parishad representatives (the lowest administrative unit of the local government), hardware shops, and technicians. To explore and raise (potential) interest of villagers, a survey of 134 households at Bangala was conducted. Survey findings revealed that most households (91.8%) had shallow hand pump tube well, of which 97.6% was contaminated by arsenic. It was found that the mean distance of the households from the community spot where SAR was installed was 392.5 metres. The average household size was 5.5 members and the amount of drinking water needed per household was 17.9 litres per day. Therefore, the experimental SAR unit had the ability to serve 85% of surveyed households.

Primarily, the survey raised interest of potential SAR users; for instance, 17 households (12.7%) immediately showed willingness to be involved in the experiment, whereas 6 households (4.5%) were in dilemma due to lack of consensus among household members. Once SAR was installed at a private location inside a house (the designated caretaker), villagers (mostly women) from 30 different households started collecting arsenic safe drinking water during the period of free trial. This happened because the working prototype of SAR itself performed as a symbol of safe drinking water and the location where SAR was installed became a physical space for social gatherings. Two months after the SAR installation, 17 households formed a five-member committee, including the caretaker (owner of the spot), cashier and three members. Meanwhile, after being informed about it by the local DPHE office, an outsider from a distant village came to visit the SAR unit with the hope of installing it in his own house, financed by his own money (Meeting # 5, 24 October, 2014). In addition, the experiment also attracted the attention of several persons from other villages and local NGOs (Interview # 29, 6 December, 2014).

This suggests that real world experiments with SAR served as communication and conversation tools to build support and legitimacy by raising actors' interest and enrolling new actors, therefore the experiments did indeed function as a *Window*. We turn next to considering whether SAR also fulfilled the third and final function: serving as an *Agent of change*.

5.5.3. Experiment as *Agent of change*

Real world experiments function as an *agent of change* only when the actors' practices and behaviours are altered to make the innovation successful. In the first SAR experiment, alternation of users' practices and behaviours was not the intention, for three reasons. First, users at Payob preferred a ready-made solution to their arsenic problem, instead of participating in an experimental technology like SAR that may or may not show success in solving the problem. Secondly, due to ethical reasons, drinking water from the experimental SAR unit was formally prohibited in the first experiment, which did not benefit the users directly, and hence also could not stimulate behavioural changes. And third, potential users were not convinced about the outcome of the experiments where only iron was successfully removed. As such, one respondent (FGD # 5, August 27, 2013) clearly stated that "... you people are emphasising … removal of iron instead of arsenic for the sake of experiment, but for us, it is not an issue, we only want a technology that will benefit us by removing arsenic." Although potential users and community representatives were informed about the risks associated with drinking arsenic rich water, this information was not sufficient to stimulate behavioural changes.

In experiment B, six months after the installation of the SAR, only three out of 17 households were continuing to use the SAR unit and no new users showed interest to join. The main reason behind this decline was users' unwillingness to spend money for the monthly operation cost (for instance, the electricity bill). It is evident that operation and maintenance of a community-level arsenic mitigation technology warrants a change in users' longstanding practice of having access to drinking water in their own backyard, at no monthly cost. Although, initially the location where SAR was installed was used as a physical space for social gatherings, later users were unwilling to collect water from a privately owned community spot situated inside a household. Furthermore, many users who used the spot as a physical space for social gathering were discouraged from spending money to collect water from a technological solution located in someone else's household, which was related to their social status as well. Hence, users' initial willingness and openness to SAR experimentation could not be sustained. Overall, the second experiment B hardly resulted in any changes in users' practices of drinking arsenic-contaminated water from shallow tube wells. Equally, the changes in users' behaviour required for long term success of a community-level SAR unit did not occur. Such changes would require, for example, a shift from a household to community-level location (impeded by concerns relating to distance, time, physical labour and socio-religious norms); from a single source for diverse uses to multiple sources for diverse uses (for instance, SAR treated water for drinking and cooking, with the household contaminated tube well water for other purposes such as bathing); and from unlimited to limited amounts of drinking water. Such relatively far reaching changes were not stimulated by either of the experiments. In addition, using arsenic safe water for the purpose of cooking was neglected by 12 households, who continued to view arsenic safe *drinking* water alone as enough to protect them from being exposed to arsenic-related diseases (Interviews # 25, 26,17 July, 2014).

The question of ownership of the community-level technology was a crucial aspect of experiment B. In practice, what was intended to be a community-level technology turned into a private technology, with the host household (caretaker) became *de facto* owner of the technology. Additionally, collection of drinking water from someone else's household was eventually considered a matter of shame, which did not stimulate sustained changes in behaviour. In many cases, the caretaker ignored the importance of organizing a special meeting to settle users' concerns over operation costs and/or to increase the number of users. In this regard, once the experiment came to a formal end, the research team could no longer assess or explore behavioural changes. The motivation provided to users and community representatives through consultation meetings and informal discussions did not contribute to alter actors' practices and behaviours. As a consequence, the real world experiments with SAR could not fulfil the third function of socio-technical experiment: *Agent of change*.

5.6. Discussion and Conclusion

This paper examined whether and to what extent real world experiments with SAR in rural Bangladesh can be conceptualized as a socio-technical experiment. Through analyzing two real world experiments with SAR, we focused on whether and to what extent they fulfilled the three functions of serving as a *Living lab*, *Window* and *Agent of change*.

Table 5.3: Functions of socio-technical experiments: Assessing SAR performance

Functions	**The extent to which each function was fulfilled**
Living lab(local shifts and barriers in culture (way of thinking, values, reference framework, etc.), practices (habits, ways of doing things, etc.) and institutions (norms, rules, etc.) are identified via the experiment	The experiments revealed that existing culture (belief systems, practices and institutions) have a preference for a technology linked to the household-level shallow hand pump tube well, which is regarded as the reference technology. Various aspects of culture, beliefs, practices and institutions relevant to assessing the prospects for future successful deployment were identified via SAR experiments.
Window (experiments are utilized as communication and conversation tools to build support and legitimacy by raising actors' interest and enrolling new actors)	Working prototype (and visuals also) was used as communication and conversation tools; the experimental SAR community spot was used as a physical space for social gathering; initially, the second experiment (B) in particular raised users' interest and enrolled new users. However, the first experiment (A) did not achieve a breakthrough in removing arsenic from drinking water to desired levels, causing potential users to lose interest.
Agent of change(actors' practices and behaviours are altered to make the radical innovation successful)	The experiments failed to alter the practices and behaviours of the users that would be necessary for niche development and scaling up of the SAR innovation.

Source: Authors analysis, based on fieldwork 2011-2014

With regard to *Living lab*, findings reveal that the technical performance of SAR in removing arsenic from groundwater sources eventually improved in the experiments. Another key finding was that rural people resisted the integrated design of arsenic and iron removal. This suggested that if an experimental technology is introduced in a village, it encounters opposition from the existing socio-technical regime that favours the reference technology (Hossain et al., 2015). The resistance observed had some other explanations as well. Considering shallow hand pump tube well as a reference technology, three barriers to accepting SAR prototypes were identified: first, higher installation cost of SAR; second, unavailability of spare-parts (for example, disk aerator and flow controller) in the local market; and third, lack of adequate local knowledge relating to installation and repair of SAR units. Furthermore, SAR required some basic changes in existing practices related to safe drinking water (for instance, shift from household-level to community-level technology, single purpose versus multiple purpose of use, convenience etc.) in rural areas. Yet various existing norms and institutions did not favour the introduction of a community-level drinking water technology like SAR. The reasons behind these were: households were not willing to spend money, the existing social structure did not encourage people to form a community organization to maintain a community-level drinking water technology and existing socio-religious norms militate against women and girls fetching water from a distant community location. The barriers to wider acceptance of experimental SAR at a community level in rural Bangladesh thus included monthly operation costs, community organization dynamics and socio-religious norms. These findings are also supported by analyses of other arsenic mitigation options in Bangladesh (e.g., Hoque et al., 2004; Shafiquzzaman et al., 2009;Mosler et al., 2010; Hossain & Inauen, 2014). Given however that the barriers linked to culture, practices and institutions were further identified and/or confirmed by testing and learning from the SAR experiments, we conclude here that the real world experiments with SAR fulfilled the function of *Living lab*.

In addition, the real world experiments with SAR fulfilled the function of *Window* because experiments were utilized as communication and conversation tools. In the experiments, several strategies (use of visuals of prototype and working prototype) were relied upon to raise potential user interest and to enrol new users, with the exception of integrated arsenic and iron removal prototype, which remained in the lab and was not tested.

With regard to *Agent of Change*, the SAR experiments clearly failed to influence those users' practices and behaviours necessary to ensure success. With regard to existing practices, teh pull of the shallow tube well as reference technology was too strong, even as the lack of visible benefit from the SAR experiments contributed to the lack of behavioural changes. Besides, once SAR became functional, using community-level technology was seen as a detrimental to a potential user's social status. This revealed, as well, that ownership of the community-level technology is a crucial aspect of a real world experiment.

Additionally, once the experiment came to an end formally, the research team could no longer assess or explore required behavioural changes. The motivation provided to users and community representatives through consultation meetings and informal discussions did not contribute to alter actors' practices and behaviours. In this connection, several changes required in existing practices and behaviours of potential users were identified via the experiments, but did not materialize. These included shifts relating to paying for (previously free) drinking water, compounded by inconveniences relating to distances needed to access water. Wider adoption of SAR would also have required a re-conceptualization of ownership of community-level technology (notions of caretaker versus other beneficiaries) (see also Sultana, 2006; Kabir & Howard, 2007; Johnston et al., 2010; Milton et al., 2012). In particular, our analysis shows that commonly deployed notions of 'community'– as consisting of all households in a village– underpinning community-level arsenic mitigation technologies fail to capture the complex heterogeneity embedded in a social structure. With these barriers and hurdles to behavioral change, the real world experiment with SAR failed to serve as an *Agent of change*.

In sum, our analysis reveals that real world experiments with SAR to date in rural Bangladesh fulfil the functions of *Living lab* and *Window,* yet fail to act as an *Agent of change.* Hence, these SAR experiments cannot be characterized as full-fledged socio-technical experiments, as per transition theory. Although the real world experiment with SAR was able to test a prototype and improve its technical functioning, required changes in potential users' practices and behaviours did not materialize. Partly, this is because the real world experiments with SAR were understandably concerned, in the first instance, with the technical aspects (for instances, water quality parameters necessary for spot selection, improvement in technical performance and design), despite best efforts from researchers to also simultaneously consider social aspects (such as awareness, motivation, community organization, spot selection by users' choice, required behavioural change, post-installation support, etc.). For instance, as mentioned earlier, location and spot selection to install SAR units was primarily determined by technical aspects. Therefore, our findings suggest that a balance between technical and social aspects remains a crucial issue, linked to the long-standing debates about the dominance of technical aspects or technological determinism in science-society interactions.

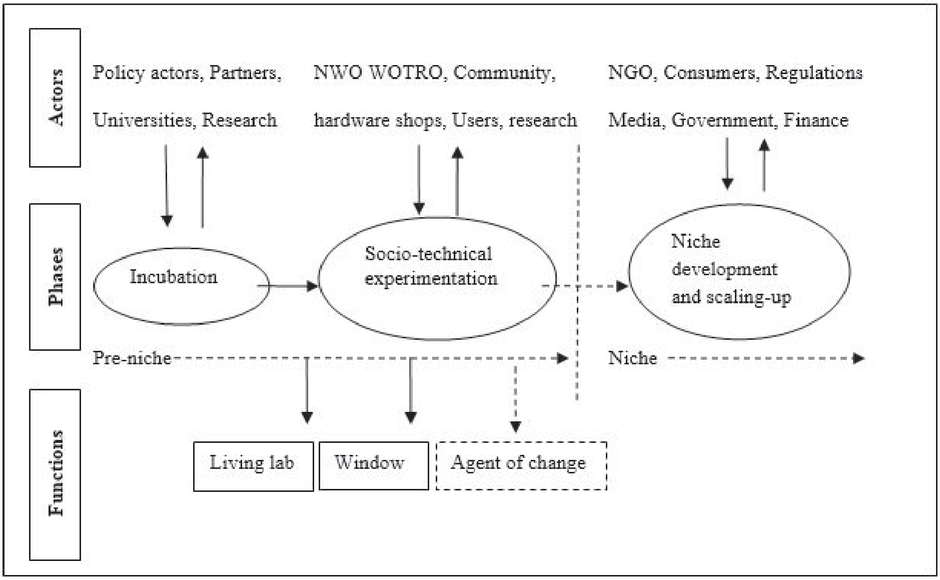

Figure 5.5: Distinction between pre-niche and niche: fulfilling pre-niche conditions as a prerequisite to niche development

Our analysis also has implications for the role that small-scale socio-technical experiments play in the emergence of radical innovations and their establishment as technological niches, including in a developing country context (see Figure 5.1). In particular, we find that existing analyses of technological niches do not pay adequate attention to what can be referred to as "pre-niche" activities, including incubation and socio-technical experiments (see also Geels, 2002). In this regard, a demarcation between pre-niche and niche formation in testing and uptake of radical innovations can be useful (see Figure 5.5). Our analysis reveals that, as SAR experiments are not yet serving as *agents of change,* they are not yet fulfilling the pre-niche functions of sociotechnical experimentation, and hence a transition to niche formation has not occurred for SAR technology. This implies that if the three functions *were* fulfilled, this would have facilitated transition of the SAR prototype from a pre-niche to a niche stage.

One way forward to facilitate sociotechnical experiments to serve as agents of change could be to find ways to extend the research project into a "non-research" phase, when local practitioners or local NGOs (i.e. non-researchers) can stay engaged with the experiments, as a way to continue to distil lessons and identify levers for behavioural changes. An alternative would be to replicate the experiments (in adapted form) in other areas, in order to further test the prototype as a way to move towards niche formation and scaling-up. In this context, one looming consideration is whether Bangladesh will set the WHO guideline value of 10 μg/L as an acceptable limit of arsenic level in drinking water.[47] In that case, SAR would need to achieve this new target. Results of alternative SAR operations presented in Rahman et al. (2014) showed that arsenic levels in the extracted water were close to the WHO guideline value for considerable volumes. It was also recommended by Rahman et al. (2014), that a combination of all alternative SAR operations may yield better arsenic removal and bring the WHO guideline value potentially within reach. Therefore, more experiments with combined alternative SAR operations may be required to check whether the WHO guideline can be reached. Yet, fulfilling the new target value will also require further shifts in behaviours and practices to be achieved by the experiments, in order to function as *Agent of change*.

If the real world experiments with SAR are to qualify as socio-technical experiments, three limitations need to be overcome. First, the actors (researcher and users) involved in design need to apply the framework of socio-technical experiment and its sequences (for instance, incubation, socio-technical experimentation, etc.) as well; second, researchers and funding agencies need to consider how the experiments can be conducted once the project is over; and third, a separate department established by the government might be necessary to monitor and support real world experiments with radical innovation and niche formation. Furthermore, our findings suggest that a strong community organization, in association with GOs and NGOs, is important to supporting sociotechnical experiments with radical innovations. Finally, our findings also point to the utility of distinguishing (both in theory and practice) between niche and pre-niche stages of experimentation to identify specific dynamics of each.

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[47] Minutes of the Local Consultative Group WSS Sub-Group meeting consisting of decision making officials of the government of Bangladesh and the international development partners working on water and sanitation issues held on 19 July 2012, Retrieved from: http://www.lcgbangladesh.org/WaterSan/minutes/Minutes%20-%20LCG%20Meeting%20-%2019072012.pdf, Accessed on: 23 November, 2014

To conclude, instead of emphasizing only the limited success in application and scaling-up of radical innovations in rural Bangladesh, this paper has also highlighted the importance of studying real world experiments, in the search for sustainable socio-technological solutions.

Chapter 6

Discussion and conclusion

6.1. Introduction

This study has analyzed socio-technical changes to the safe drinking water regime in rural Bangladesh, following the discovery of arsenic contamination of shallow tube well drinking water. The main objective was to explain the success or failure of socio-technical changes linked to experimenting with and deploying various arsenic mitigation technologies, in order to re-stabilize the drinking water sector of rural Bangladesh in the post arsenic contamination phase. In doing so, it sought both to go beyond and deepen the analysis of "social acceptability" of various technological options, by exploring both the user (rather than only the expert) perspective on social acceptability and embedding this into a broader analysis of the dynamics of socio-technological change, using the analytical lens that draws on, inter alia, transition theory. A key aim was also to analyze the dynamics of technological change as envisioned within transition theory, including sociotechnical regimes, niches and landscapes, in a rural, developing country context.

The following four questions were developed to achieve the research objectives:

1. How do users understand social acceptability of three diverse arsenic mitigation technologies (deep tube well, improved dug well and Sono filter)?
2. Why and how does a technological innovation (deep tube well) designed to provide safe drinking water become dominant in the context of arsenic contamination?
3. Why did the promising take-off of the household arsenic removal Sono filter technology stagnate and fail to establish itself as a niche technology?
4. How do novel experimental technologies (such as the Sub-Surface Arsenic Removal) function as emerging socio-technical experiments in rural Bangladesh, and (how) can they re-stabilize the existing safe drinking water regime?

A conceptual framework derived from transition theory, presented in Chapter 1, was applied to answer these questions. This was based on analyzing social acceptability within a broader context of a changing socio-technical regime, the dynamics of pre-niche and niche formation and real world experiments to analyse changes in the socio-technical regime related to arsenic mitigation technologies in rural Bangladesh.

This concluding chapter is organized as follows. Section 6.2 distills the answers to the research questions by drawing on the detailed analyses of each undertaken in chapters 2-5, and also presents overarching findings that cut across the empirical chapters. Section 6.3 contains methodological reflections, including the question of internal validity, and Section 6.4presents theoretical reflections. Finally, Section 6.5 and Section 6.6 discuss the generalizability of this research and outline implications for arsenic mitigation and recommendations for policy and practice, as well as directions for future research.

6.2. Explaining socio-technical changes in the post-arsenic safe drinking water regime in Bangladesh: research findings

6.2.1. Analyzing user perspectives on social acceptability of arsenic mitigation technologies

As discussed in the introduction to this thesis, understanding *user* perspectives on the social acceptability of arsenic mitigation technologies was a key gap in the literature, with much focus of social acceptability to date focusing on expert opinions of factors shaping acceptability. The analysis in this thesis highlighted that not all factors shaping social acceptability posited in the literature were found to be equally important by users. In general, availability and affordability, as well as water use practices were the most crucial in securing acceptance of the three arsenic mitigation technologies examined with regard to social acceptability as perceived by users. As the further analyses of the deep tube well and Sono filter undertaken in subsequent chapters revealed, the remaining factors, including ease of use, risk awareness, and water quality beliefs, have had variable impact on social acceptability, with a greater impact on (low) user acceptability of the Sono filter and improved dug well (as compared to the deep tube well).

The analysis shows that the deep tube well is regarded as highly acceptable by most of its users. Improved dug well and Sono filter are seen as less acceptable. In conclusion, the analysis suggests that user understanding of what constitutes social acceptability provides an important lens through which to grasp why certain technologies are judged to be more acceptable than others. Since thetechnological innovations studied for social acceptability are neither of similar type, nor are they implemented and promoted in a similar way, the findings of this thesis highlight that the technology’s context of development and its context of use are to be taken into account while analysing social acceptability of a technological innovation and its further dissemination (or not). It implies the need, furthermore, for understanding social acceptability as a dynamic rather than a static process.

Although the framework of socio-technical regimes does not include social acceptability as a distinct concept, the findings of the first three empirical chapters, taken together, shed further light on the importance of user perspectives on social acceptability. In particular, they highlight the interconnectedness of social acceptability with socio-technical regime dynamics (and niche formation), pointing to the need to study these inter-relationships and how they shape the dynamics of technological innovations, as a key finding and contribution of this thesis. The analysis reveals that technological innovation with higher social acceptability by the users also translates into dominance in a re-stabilized socio-technical regime and vice versa (as is the case with the deep tube well technology). On the other hand, radical (technological) innovations still at the niche (or pre-niche) experimental stage often struggle to establish themselves and scale up, with one reason also being the lack of prospects to secure user social acceptability at these early stages.

6.2.2. Explaining the dominance of incremental innovations in the socio-technical regime

Building on the insights on user perspectives on social acceptability of arsenic mitigation technologies, this thesis has also sought to explain in greater depth the dynamics of change versus stability in a socio-technical regime, including why specific technological options come to dominate in a re-stabilized regime. This was done by going beyond a social acceptability lens to also identify change mechanisms, as well as the magnitude of change, in seven socio-technical regime dimensions derived from transition theory. These change mechanisms were analysed in the case of the deep tube well, to explain why this option came to dominate in the post-arsenic crisis phase.

In particular, the thesis finds that several sociotechnical regime dimensions, including inter alia, technological attributes, symbolic meaning, industry structures, and techno-scientific knowledge, were supportive of the dominance of the deep tube well. Besides, adaptation in user practice (a shift from ‘private’ to community facilities), a reorientation in infrastructures (through reorganisation, without including new members) and the introduction of policies and practices (through institutional, regulatory, and financial supports) also helped to secure the dominance of the deep tube well.

This analysis indicates that with the dominance of deep tube well technology, a transformation took place in the existing safe drinking water regime after arsenic contamination was discovered. Although the deep tube well technology was introduced in Bangladesh well before the arsenic crisis emerged, and when the safe drinking water regime was still stable and configured around the shallow hand pump tube well, its resultant destabilisation because of arsenic contamination of shallow tube wells helped to ensure a growing dominance of the deep tube well as a result of several change mechanisms at play.

This suggests, as well, that the application of incremental (rather than necessarily radical) innovations to re-stabilize a socio-technical regime is a viable and appropriate approach in a developing country context. Analysing how an incremental innovation came to dominate also highlights the importance of studying the dynamics of the relationship between the technological innovations at both niche and regime level in the search for sustainable socio-technological change. This point was further reinforced through the analysis of new and more radical innovations, the Sono filter and the experimental SAR technology, as discussed below.

6.2.3. Explaining stagnation in niche formation of radical innovations in de-stabilized socio-technical regimes

Using strategic niche management (SNM) as an analytical tool, this thesis further explained that despite its ability to remove arsenic from drinking water supplies in rural Bangladesh, a radical innovation (illustrated by the case of the household arsenic removal filter, the Sono filter) stagnated after a few years, despite a promising early start. In addition to the insights provided by the user perspectives on social acceptability noted above, SNM as an analytical approach helped to highlight thata variety of factors, including lack of support from policy and market actors, and the need to change existing user practices, hindered successful Sono filter niche formation. SNM as an analytical tool thus proved useful in explaining the stagnation of niche formation of a radical innovation and its inability to restructure and restablize the post-arsenic socio-technical safe drinking water regime. Furthermore, the analysis also showed how this radical innovation could not compete with the evolving expert and user driven preferences for non-filter-based technologies (especially deep tube well), which had been part of the socio-technical drinking water regime even before the arsenic crisis hit.

As such, this thesis adds to the existing framework of SNM by showing that niche formation for radical innovations cannot succeed in contexts where a hybrid set of actors involved in a socio-technical regime deliberately endorse unequal competition among technological options, in order to prioritize and promote incremental innovations. This also contributed to its relative lack of social acceptability, including from a user perspective. An important question for further research flowing from these findings is the need to identify conditions under which a radical technology *can* compete with incremental innovations in establishing itself as a niche option with the prospects for scaling up in the future.

6.2.4. Analysing the role of pre-niche real world experiments in re-stabilizing socio-technical regimes

This thesis further sheds light on the conditions under which the newest technological options, still at the pre-niche field experiment stage, can fulfil the functions of a real world experiment, and thereby aid in stabilizing the socio-technical regime as well.

In particular, the analysis examined whether real world experiments with sub-surface arsenic removal (SAR) technology in rural Bangladesh fulfilled the experimental functions of serving as a living lab, window, or agent of change. The findings, as noted in chapter 5, revealed that the SAR technology being tested was able to fulfil the functions of a *Living lab* and *Window,* yet failed to act as an *Agent of change.* Hence, these SAR experiments were not full-fledged socio-technical experiments, as per transition theory. Although the real-world experiment with SAR was able to test a prototype and improve its technical functioning, required changes in potential users' practices and behaviours did not materialize.

Partly, this is because the real world experiments with SAR were understandably concerned, in the first instance, with the technical aspects (for instances, water quality parameters necessary for spot selection, improvement in technical performance and design), despite best efforts from researchers to also consider social aspects simultaneously (such as awareness, motivation, community organization, spot selection by users' choice, required behavioral change, post-installation support, etc.). Therefore, our findings suggest that a balance between technical and social aspects remains a crucial issue, linked to the long-standing debates about the dominance of technical aspects or technological determinism in science-society interactions.

Going beyond this, our findings also highlight the need to focus attention on what can be referred to as “pre-niche” activities, including incubation and real world experiments. In this regard, this thesis has shown that in analyzing technological niches, a demarcation *between pre-niche and niche formation* can be useful. This is particularly relevant, given that the existing framework of SNM cannot fully explain the early stages of experiments (see Geels, 2002). Added to this, frameworks for studying social acceptability are also limited in their ability to assess social acceptability of experimental technologies at pre-niche level. This also implies a question for further research: how a journey from pre-niche to niche to scaling up to become an integral part of a socio-technical regime occurs, and how it can be facilitated where necessary.

6.3. Reflections on methodology

Methodologically, the crucial challenge for this research was to maintain the balance between social and technical aspects of the innovations being studied. This challenge was mitigated, to some extent, by composing a multi-disciplinary research team with social sciences and technical sciences both well represented. During the period of instrument development, several drafts of the checklists and questionnaires were consulted with multi-disciplinary research experts. Collection of data for technological innovations already deployed in Bangladesh, such as Sono filter, deep tube well and improved dug well (chapter 2, 3 and 4), was easier than that for real world experiments with SAR (chapter 5). In particular, involving multiple stakeholders to participate in field experiments, and then following up on developments, monitoring the process and interviewing participants at the same time was a complex task, which was further intensified due to socio-technical uncertainties with the experiments, and time-bound nature of the research project. These complexities were dealt with by deploying additional research assistants who were in regular connection with the water management committees and other relevant stakeholders.

Another important question was how the internal and external validity were ensured in this research. Internal validity of findings has been secured through triangulation, prolonged periods of field work, reviews, consultation with diverse groups of experts and reliance on both qualitative and quantitative approaches. For triangulation, standardized checklists for multiple techniques of data collection were used to enhance the diversity and quality of data obtained from multiple actors. The instruments developed for survey, in-depth interview and focus group discussion were finalized after piloting, peer consultation and experts’ opinion. Multiple stakeholders were interviewed to ensure the cross validation of information. For example, the number of technologies disseminated in an area was confirmed both by implementing agencies and technology receivers. Data analysis and preliminary findings were presented in project meetings, seminars and conferences, where experts’ opinions confirm findings as credible and reliable.

Besides, in order to increase external validity, selection of a wide range of technological innovations in diverse sociotechnical settings as case studies was a strategy. It is worth mentioning that differences of actors (government, NGOs and community members) in disseminating the technological innovations were taken into account. In addition, case studies of the selected technological innovations and a sociotechnical experiment were analyzed in an in-depth manner. These findings were theoretically validated in the context of developing countries by testing the applicability of a theory-driven analytical model originating in OECD countries.

The extent to which the findings of this thesis are generalizable is of immense importance in relation to external validity. In seeking to secure generalizability, the analysis was complemented with a wide range of literatures. For the three empirical chapters (Chapters 2-4), the reviews (as part of publishing in peer reviewed journals) highlight that the core arguments of these chapters reflected the facts relating to socio-technical changes taking place in the safe drinking water domain elsewhere. Similarly, the analyses developed in these three chapters are compatible with existing theoretical and empirical understanding aligned with sociotechnical aspects of arsenic contamination. The schematic framework (social acceptability from a user's perspective) proposed in the empirical chapter (2) is a contribution of this thesis that is also applicable to understanding social acceptability of any technological innovation in other contexts. While investigating socio-technical experiments (chapter 5), the theory-driven schematic framework of sociotechnical 'real world experiments' allowed for development of the idea of a 'pre niche', which is new but seems to be applicable for studying socio-technical changes in other domains.

More generally, the schematic frame works developed in the thesis, deriving from transition theory, and their application to investigate sociotechnical changes in a rural, developing country context, is pioneering for the case of understanding arsenic contamination. This can also be applicable to study sociotechnical changes in diverse settings beyond Bangladesh. Under the broader spectrum of transition theory, this thesis shows that the Multilevel perspective and its aligned concepts (social acceptability, niche management, dominance in regime, sociotechnical experiments and scaling up etc.) are applicable in a developing country context. While applying these conceptual frameworks, this thesis synthesizes that various adjustments among the concepts are required: a) the interconnectedness of social acceptability with socio-technical regime dynamics (and niche formation); and b) a demarcation *between pre-niche and niche formation* in sociotechnical experiment. An important question emerging from this analysis is to identify conditions under which a radical technology can compete with incremental innovations in establishing itself as a niche option, while seeking to secure social acceptability. This also implies a question for further research on the extent to which social acceptability of technological innovations at niche (and pre-niche) and regime level can be analyzed by applying existing frameworks of social acceptability and multilevel perspectives, or whether more integrated perspectives are needed. In addition, this thesis suggests that transition theory with these amendments also can be applicable in other domains (for example, energy, transportation, sanitation etc.). Finally, the insights of this thesis contribute to further investigation of the dynamics of society-technology interactions in diverse contexts.

6.4. Reflections on transition theory

This thesis has applied various concepts and approaches derived from transition theory based on the assumption that it would be useful to analyse development and testing of technological innovations for arsenic mitigation. This section briefly highlights how and to what extent the application of transition theory has contributed to a better understanding of sociotechnical changes in the safe drinking water sector of rural Bangladesh.

Firstly, transition theory originated in developed countries, such as the Netherlands, as a novel framework to understand sociotechnical changes (Caniëls & Romijn 2008; Oyake-Ombis, 2012). This was accompanied by a conceptual shift from ‘technology’ to ‘technological innovation’, which has enabled a wide range of socio- aspects of technological innovations to be studied. As applied to a developing country context, this lens has shed light on the complex changes taking place in the rural drinking water regime in rural Bangladesh.

Second, in complementing this analysis of sociotechnical regimes, and the role of incremental and radical innovations herein, the thesis has also advanced a “user’s framework” on social acceptability of various technological options that generates new insights on the conditions under which technologies can become widely accepted and hence be scaled up. At the same time, the analysis here highlights that social acceptability is a dynamic rather than a static process, which implies that both incremental and radical technological innovations with initially lower user acceptance can, under specified conditions, overcome hurdles to social acceptability.

Third, the concept of social acceptability is not included in the framework of Multi-Level Perspectives (MLP) in transition theory, however, there are many elements in a sociotechnical regime, such as technological design aspects, user practices, symbolic meaning and techno-scientific knowledge that are also embedded in the conceptualization of social acceptability. Hence, the thesis has highlighted the interconnectedness of social acceptability with sociotechnical regime dynamics (and niche formation) in shaping the prospects of a technological innovation.

Fourth, measuring the social acceptability of niche technology and dominant technology (already in sociotechnical regime) cannot easily be done by using a unique analytical framework. In this regard, separate analytical framework needed to be developed considering their context of origin, implementation and dissemination. At the same time, how to design the evolving social acceptability of pre-niche technologies remains a theoretical and empirical puzzle that needs further analysis.

Fifth, the Strategic Niche Management (SNM) approach has proved useful in explaining the stagnation of niche formation of such radical innovations, and their inability, therefore, to restructure a sociotechnical regime. Although the existing framework of SNM does not accord a strong role to a niche actor/manager, this thesis finds that an emerging set of hybrid actors (mainly regime actors) are crucial to shaping niche establishment and consolidation.

Sixth, this thesis contributes to the operationalization of the concept of real world experiments, their functions and how they are related to re-stabilization of a sociotechnical regime. It proposes an analytical distinction between pre-niche and niche, not yet identified in the literature to our knowledge. This enriches SNM related analyses, which has not always focused on the early stages of experiments (see Geels, 2002). By studying the case of SAR, this thesis has shed light on the roles that experiments play in the process by which radical innovations come to occupy a niche, with the prospects for scaling up. Drawing on the pre-niche and niche distinction, this implies that the success of a sociotechnical experiment depends on successful real world experimentation in a pre-niche phase and its smooth transfer to niche formation.

Seventh, there is a common understanding among the transition theorists that stable sociotechnical regime does not provide opportunities for niche innovation. This thesis, however, argues that a partially stable sociotechnical regime can create avenues for changes. In this connection, the question of opportunities for niche innovation in a stable sociotechnical regime has been raised.

Finally, this thesis reveals that application of incremental innovation to re-stabilize a sociotechnical regime is useful (Geels & Kemp, 2007). Furthermore, instead of emphasizing only the limited success in application and scaling-up of radical innovations in rural Bangladesh, this analysis also highlights the importance of studying the functions that real-world experiments with radical innovations need to fulfil in order to contribute to sustainable socio-technological solutions.

6.5. Reflections on arsenic mitigation in Bangladesh

This thesis has implications for stabilizing the safe drinking water sector in rural Bangladesh. From a technology user's perspective, the installation of an adequate number of deep tube wells at convenient locations is likely to be the most socially acceptable option of those currently disseminated. Improved dug well is the least viable arsenic safe technology, given its marginal social acceptability. With regard to the Sono filter, despite having problems associated with availability, ease of use, affordability and water use practices, such filters *could* gain greater social acceptability in those regions where the deep tube well is not feasible (e.g. for geo-hydrological reasons), provided such aspects are addressed.

Similarly, many other technological innovations such as the pond sand filter, rain water harvesting, and additional filter technologies that are not studied in this thesis show the least acceptability. Given that piped water supply is the most acceptable technology in an urban context, it is also considered as a potential long-term solution for arsenic mitigation in rural Bangladesh as well, although the hurdle is that it requires high capital investment (Hoque et al., 2004; Kabir & Howard 2007; Shafiquzzaman et al., 2009; Inauen et al., 2013; Hossain & Inauen, 2014). Related to this point, this thesis pointed out that social acceptability of a given technological innovation is not a static decision but rather it is a dynamic process. Hence, making a technological innovation more acceptable not only depends on its users but also on policymakers, implementation agencies, development partners and market actors, who shape the context within which user-based social acceptability is generated.

Although the Bangladesh government's National Arsenic Mitigation Policy and the Implementation Plan for Arsenic Mitigation have clear preference for surface water technologies, like improved dug well or pond sand filters, in practice the government has prioritized community level non-filter technologies (for instance, deep tube well), instead of household and community-level filter-based technologies.

Existing sociotechnical drinking water regime in many ways supports the dominance of deep tube well technology. With this dominance, a transformation took place in the existing regime after arsenic contamination. On the other hand, as this thesis has shown, a variety of factors, including lack of support from policy actors and market actors, and the need to change existing user practices, hindered the success of filter technologies. As such, filter technologies could not compete with the evolving preferences for non-filter-based technologies (especially deep tube well), which was part of the sociotechnical drinking water regime even before the arsenic crisis hit. Thus, despite initial success, the introduction and dissemination of the filters could not significantly alter the sociotechnical safe drinking water regime in Bangladesh.

This thesis also suggests that the filters *can* have a (limited but important) role to play in mitigating the arsenic crisis in Bangladesh, as there will always be locations where deep tube well technology is not feasible to deploy (Milton et al., 2012). For these filters to play such a role, however, key actors (for instance, the government, development partners and NGOs) in the network need to advance filter production, marketing, and dissemination.

This thesis also finds that experiments with radical technologies in arsenic mitigation continue to be important, while raising new questions relevant to assess acceptability and sociotechnical change. For instance, what and how many households should constitute a 'community' has emerged as a contested issue in determining the service coverage for a community-level arsenic mitigation technology. Another challenge is that real-world experiments, in this case with SAR technology, is often designed and implemented in a manner that is more focused on technical aspects (improvement in technical performance and design) than on social aspects (awareness, motivation, community organization, spot selection, behavioural change, post-installation supports, etc.). Other long understood challenges include the project-dependent and time-bound nature of experimental processes through which radical technologies are developed and matured. Hence, a revised framework of sociotechnical experimentation consisting of pre-niche and niche can be effective to assess conditions under which to mature the technological innovation once an experimental project is over. Furthermore, the involvement of various actors from the government, industries, development, policy and media is crucial to carryout, monitor and support long-term experiments with radical technologies.

There is an understanding that urban water infrastructure receives more importance than that of rural areas. In this situation, despite all ecological and geological differences, a comprehensive rural water supply plan is needed to be developed with high priority. In addition, to what extent the idea of niche formation through non-state actors can be successful in the context of Bangladesh raises many questions, where a few NGOs seek to ensure maximum water coverage. Considering the success of NGOs in the sanitation sector of Bangladesh, the state actors along with non-state actors can cooperate to develop and implement niche formation in the drinking water sector.

Finally, an emerging concern is if the WHO guideline value of 10µg/L levels of arsenic contamination is set as the national standard of the acceptable limit of arsenic in drinking water in Bangladesh as well, then existing and future arsenic removal filters would have to achieve this revised standard. As a result, all screened and unscreened shallow hand pump tube wells would need to be tested again, which is a huge task. Additionally, several technical factors including geographical variability, diverse geohydrological conditions, soil structure and uncertain spatial distribution of arsenic in groundwater serve as constraints in developing a unique mitigation technology applicable to all arsenic affected areas with diverse socio-economic settings (Hoque et al., 2006, Ravenscroft et al., 2009 , Johnston et al., 2010, Mosler et al., 2010, Milton et al., 2012). Therefore, understanding sociotechnical changes related to arsenic mitigation technologies continues to be vitally important and timely in efforts to stabilize the safe drinking water domain in rural Bangladesh.

6.6. Recommendations for policies and further research

The findings of this thesis yield certain implications for the successful implementation of arsenic mitigation policy, in particular, by showing that incremental innovations have an important role to play in mitigating the arsenic crisis in rural Bangladesh. Groundwater arsenic contamination of shallow hand pump tube well is a complex problem, which has interconnectedness with innovations and safe drinking water sector, coupled with environmental, social, and health issues. Failure to address this complex problem at policy level further complicates the mitigation efforts (Atkins et al., 2007, Milton et al., 2012). As such, development and dissemination of region-specific arsenic mitigation technologies remains a crucial challenge, which deserves more attention from the government of Bangladesh and the development partners. Although the National Arsenic Mitigation Policy (NAMP) was launched in 2004 with the promise to ensure access to safe water for drinking and cooking in all arsenic affected areas through installing arsenic mitigation technologies, the timeline to achieve the target is not specified in the Implementation Plan for Arsenic Mitigation (IPAM).

Despite the very area-dependent nature of arsenic mitigation technologies, NAMP proposes an arsenic mitigation programme to offer a range of technological options applicable for arsenic affected areas. However, the priority in this plan is given to surface water over ground water sources of safe drinking water (GoB, 2004a). It is mentioned in the IPAM that improved dug well and pond sand filters will be tried first, and as per the protocol deep tube wells will be the last option. The long-term goal is to introduce piped water supply systems in both rural and urban areas, as being preferable to treating surface water (GoB 2004b). This thesis and its findings suggest, however, a need to prioritize the deep tube well in the plan (and in practice).

Along with this, Bangladesh has become a fertile ground for testing and implementing household and community level arsenic mitigation technologies. As envisioned in IPAM, the government is only responsible for testing and validating the filters, while experiment, production, marketing and dissemination of these filters should be through the private sector (GoB 2004b). This thesis shows that private sector's involvement in promoting filter technologies is not adequate enough, hence an active role of the government is necessary to ensure widespread dissemination of these filters, which is not possible within existing IPAM.

IPAM advocates that in emergency areas, supply driven dissemination of community-level arsenic mitigation technologies should be commenced and completed in one year (GoB 2004b). This thesis shows that there are many highly contaminated villages where deep tube well technology is not feasible to install, nor are filters being tried. It is also said that the usual practice is to provide an emergency response without any cost-recovery. In practice, the free-of-cost installation is hardly being followed. Screening of existing shallow hand pump tube wells remains a challenge. At the same time, the success of existing technological innovations in mitigating arsenic crisis has shown limitations in relation to uncertainties about the effectiveness of alternative water supply options. Furthermore, not stopping the deployment of shallow hand pump tube well in the arsenic contaminated areas makes the situation more complicated.

At the same time, there is no particular guideline for conducting research on experimental technologies and its further development. Given that the projects or fund driven experiments are the core characteristic of arsenic mitigation activities in Bangladesh, a guideline to mature experimental technologies is expected where the coordination between GOs and NGOs would be facilitated. A separate section to guide the experimentation, development, validation and promotion of arsenic mitigation technologies would be incorporated within the arsenic mitigation policy. A separate cell for promoting and monitoring of arsenic removal technologies can be developed within the institutional framework of DPHE. It is recommended that policies and implementation plan should focus more on how to facilitate experimentation, development, and enhance the dissemination and acceptability of arsenic mitigation technologies. It must put emphasis on the involvement and coordinate all relevant stakeholders including community and take the broader complex context of drinking water sector after arsenic mitigation in relation to diverse geomorphological and social settings. Along with the development of technological innovations, policies and implementation should gain insights from the understanding of socio-technical changes to re-stabilize the drinking water sector.

As elements of a future research agenda, the analysis here could be usefully augmented by further research on the interrelatedness of the factors shown here to be important to securing user-centered social acceptability, as well as comparative studies of social acceptability of diverse arsenic mitigation technologies in different geographical locations. It would also be useful to undertake such analyses in countries beyond Bangladesh that are grappling with the same problem of arsenic contamination of safe drinking water. Comparative analysis of arsenic contamination versus other challenges such as salinity could be instructive as well, in shedding light on how diverse sociotechnical landscapes shape the specifies of regime stability and change.

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Appendix A: Survey questionnaire and checklists: Social Acceptiblity of Arsenic Mitigation Technologies

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1. Ethnic Identity	**1.1 Bangalee**	**Others, mention:**

2. Religious Identity	**2.1 Muslim**	**2.3 Christian**	
	2.2 Hindu	**2.4 Buddhist**	

3. Name of the Interviewee		**Line#**		
4. Name of Household Head		**Line#**		
How long have you lived in this area?				
What is the technology that you use?	**1= Deep tube well 2= Dug well 3= Sono filter**			

Phone Number (if any) ☐☐☐☐☐☐☐☐☐☐☐

Date of Interviewing								
	Day		**Month**		**Year**			

5. Address	**5.1 District**		**5.4 Village**	
	5.2 Sub District		**5.5 Para**	
	5.3 Union		**5.6 Holding No.**	

Research Team	**Name**	**Date**							
		Day		**Month**		**Year**			
Name of Interviewer									
Name of Questionnaire Observer									
Name of repeat Interviewer									

Matrix 6 Answer Code for

Column 2 **1= Household Head** **2= Husband/ Wife of HHH** **3= Son** **4= Daughter** **5= Father** **6= Mother** **7= Brother** **8= Sister** **9= Daughter in law** **10= Grand son/ daughter** **11= Domestics** **Others (specify)**	Column 3 **1= Male** **2= Female** Column 5 **1= Married** **2= Single** **3= Widower** **4= Widow** **5=Separated** **6= Divorced** **7= Deserted** **Other (specify)**	Column 6 **1= Class I** **2= Class II** **10= Class X (SSC)** **12= HSC** **14= BA (Pass)** **16= BA (Hon's)** **17= MA** **18= Diploma/ Vocational** **19= Religious education** **0= No education** **Others (Specify).. ..**	Column 7 & 8 **1= Self employed (Agriculture)** **2=Service holder** **3= Business** **4=Day Labor (Agriculture)** **5= Day Labor (Non agriculture)** **6= Fishing** **7= HH activities** **8= Rural transport** **9= Student** **10= Retired Person** **11= Not Applicable** **12= Unemployed** **Others (Specify).. ..**	Column 9 **1= Yes** **0= No** Column 10 **1= Have** **0= Have not** Column 11 **1= Have** **0= Have not**	Column 12 **1= Have** **2= Have not**

6.Characteristics of Household Members

Line	**Name**	**Relationship with HHH**	**Sex**	**Age**	**Marital Status**	**Education (Year)**	**Primary Occupation**	**Secondary Occupation**	**NGO membership**	**Tubewell in HH**	**Pond in HH**	**Electricity connection**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												

7.	What are the social problems remaining mostly in your area? **Code:** 1= Unemployment 2= Crime 3= Arsenic contamination 4= Transportation 5= housing 6= Healthcare 7= Education 8= Poverty 9= Water, electricity, and waste disposal 10= Religious/ ethnic violence 11= Insecurity 12= Extortion 13= Drug abuse 14= Lack of food 15= Price hike 16= Vulnerability to natural disasters 17= Small arms problems 18= Salinity 19= River bank erosion 20= Political tension Others (specify).. ..	1. 2. 3. 4. 5.
8.	What are the social problems remaining mostly in your Households? **Code:** 1= Unemployment 2= Crime 3= Arsenic contamination 4= Transportation 5= housing 6= Healthcare 7= Education 8= Poverty 9= Water, electricity, and waste disposal 10= Religious/ ethnic violence 11= Insecurity 12= Extortion 13= Drug abuse 14= Lack of food 15= Price hike 16= Vulnerability to natural disasters 17= Small arms problems 18= Salinity 19= River bank erosion 20= Political tension Others (specify).. ..	1. 2. 3. 4. 5.

9.Household Asset lists (Non business)

	Name of asset	**Quantity**	**Price (BDT)**	**How they achieve?**
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
Code: 1= Radio/ Cassette 2= Television 3= Refrigerator 4= Cell Phone 5= Bicycle 6= Motorcycle 7= Sewing Machine 8= Chair 9= Table 10= Chouki 11= Sofa 12= Mosquito net 13= Tube-well 14= Ornaments 15= Filter 16= Tractor 17= Irrigation machine Others (Specify)..				

10.	Based on your income and food consumption, how would you rank the economic status of your HH?	1= Always deficiency 2= Occasional deficiency 3= Break-even 4= Sometimes Surplus 5= Always Surplus
Major Sources of drinking water		
11.	What is the main source of drinking water for your household?	1= Tube-well 2= Deep Tube well 3= Tara Pump 4= Dug well 5= Irrigation Pump 6= Pond 7= Canal 8= River 9= Rain water 10= Supply water Others (Specify)…..
12.	Who owns the source of drinking water?	1= Government 2= Non Government 3= Community 4= Personal 5= Neighbour
13.	Where do you collect your drinking water for your family? (If answer is 3, then go)	1= Community Spot 2= Goshthi's compound 3= Own HH 4= Commissioner's HH 5= Mosque 6= Temple Others (Specify).. ..
14.	If the ownership of the source of drinking water is yours, then when was it installed?	Years:
15.	How far is the drinking water source from your	Metre:

	HH?	
16.	How much time does it take to reach there from your HH?	Minutes:
17.	How much time do you spend daily to collect drinking water?	Minutes:
18.	Who spends most of the time collecting drinking water for your family? Who is responsible?	1=Male 2=Female
19.	How much water do you need daily for your family?	Litres:
Knowledge and perceptions about drinking water		
20.	Did anyone ever test your drinking water source?	1=Yes 0=No
21.	What was the result of the test?	1=Marked with red colour 2= Marked with green colour
22.	Who initiated the test?	1=Government 2=NGO (local) 3=NGO (international)
23.	How many years have you used the source after knowing that it was contaminated?	Year:
24.	Did you take any measures individually to remove arsenic from contaminated water or to install a safe water option?	1=Yes 0=No
25.	If yes, what were these measures?	1. 2. 3.
26.	If no, what was/ were the reason/s?	1= Poverty 2=Less important 3=Don’t know harm 4=Don’t emphasize 5=No scope 6=Don’t pose any harm Others (specify)…………
Knowledge about arsenic water and risk		
27.	Do you have any water related problem in your locality?	1=Arsenic 2=Salinity 3=Iron
28.	Do you think the smell of your drinking water is okay?	1=Yes 0=No
29.	Do you think the taste of your drinking water is okay?	1=Yes 0=No
30.	Do you think the colour of your drinking water is okay?	1=Yes 0=No
31.	Do you know about arsenic in drinking water?	1=Yes 0=No
32.	How do you know about arsenic in drinking water?	1=Radio 2=Television 3=Paper 45=Bazaar 6=Gossip 7=Govt. health workers 8=Mosque 9=Union Parishad
33.	Do you know about arsenic mitigation technology?	1=Yes 0=No
34.	When did you find out about arsenic mitigation technologies?	Years:
35.	Do you know about the negative impact of arsenic?	1=Yes 0=No
36.	Do you think that arsenic in drinking water causes health problems?	1=Yes 0=No
37.	Do you know the major symptoms when one is affected by arsenic?	1=Yes 2=No
38.	Do you see risks associated with not drinking arsenic safe water?	1=Yes 0=No
39.	If yes, how do you rank the risk you perceive?	1=Very High 2=High 3=Moderate 4=Low 5=Very Low
40.	Have you ever seen any arsenic affected people in your locality or outside?	1=Yes 0=No

41.	Did you find any organization working on arsenic mitigation at your locality?	1=Yes 0=No
42.	Did you participate in arsenic mitigation activities?	1=Yes 0=No
43.	What kind of participation have you had in arsenic mitigation activities?	1=Presence in meeting 2=Care taking 3=Repairing 4=Creating consciousness 5= Making arsenic free water reservoir Others (specify): ....
Arsenic mitigation technology: social acceptability and other issue		
44.	Do you have training relating to arsenic mitigation and technologies?	1=Yes 0=No
45.	Are you willing to receive and use the technology for getting arsenic safe water?	1=Yes 0=No
46.	Do you use the technology regularly?	1=Yes 0=No
47.	If no, why don't you use any technology?	
48.	If yes, when was the technology installed?	Years:
49.	Did the implementing agency consult with you prior to installing the technology at your household/ community?	1=Yes 0=No
50.	Who played a role in installing the technology?	1=community leaders 2= Government 3=Self 4=UP members 5= UP Chairman 6= NGO
51.	Did you start using the technology willingly?	1=Yes 0=No
52.	If yes, who inspired you?	1=Government (DPHE) 2= NGO 3=Community leaders
53.	How did you get the technology?	1=Purchase 2=Govt. assistance 3=NGO assistance 4= Cost sharing Others:
54.	Does the technology meet the drinking water needs of your household?	1=Yes 0=No
55.	Do you think that spending money to get arsenic mitigation technology is affordable for you, based on your socio-economic condition?	1=Yes 0=No
56.	Do you know the appropriate use of arsenic mitigation technology?	1=Yes 0=No
57.	Do you consider the design of technology is comfortable?	1=Yes 0=No
58.	Do you think that the operation of the technology is simple?	1=Yes 0=No
59.	Do you think that the maintenance of the technology is easy?	1=Yes 0=No
60.	Who is the responsible for operation and maintenance of the technology?	1=Own 2=Wife/ husband 3=Son 4=Daughter
61.	Does it need an electricity connection to make the technology functional?	1=Yes 0=No
62.	Does it need any additional hardware or spare-parts for functioning of the technology?	1=Yes 0=No
63.	Does it need any additional chemicals for functioning of technology?	1=Yes 0=No
64.	How much money did you spend to install the technology?	BDT......................
65.	How much money do you spend to get arsenic free water each month?	BDT ....
66.	Do you believe that the technology can remove arsenic absolutely from contaminated water or can it produce arsenic safe water?	1=Yes 0=No
67.	Does the use of technology increase the amount of water intake?	1=Yes 0=No

68.	Does the availability of arsenic free water increase your drinking water intake?	1=Yes 0=No
69.	Do you believe that the safe water brings visible improvements in your health?	1=Yes 0=No
70.	Do you think that the function of the technology is not labour intensive?	1=Yes 0=No
71.	Did the technology ever break down?	1=Yes 0=No
72.	How many times did you have to repair the technology in last 12 months?	Time:
73.	How much money did you spend to repair the technology?	BDT ....
74.	Who took the initiative to re-install/ repair the technology?	1=Household 2=NGO 3=Community 4= Government
75.	What kind of contributions have you made to reinstall the technology?	1=Financial 2=Physical labour 3=Advising 4= Spare-parts collection
76.	Do you find the technology and spare parts available?	1=Yes 0=No
77.	Do you get the same amount of water after reinstalling/ repairing the technology?	1=Yes 0=No
78.	How do you rank the expenses for arsenic safe water considering your socio-economic condition?	1=Very high 2= High 3=Medium 4=Low 5=Very low
79.	How do you evaluate the role of NGO in promoting arsenic mitigation technology?	1=Very good 2=Good 3=Medium 4=Bad 5=Worst
80.	How do you evaluate the role of the government in dissamination the technology?	1=Very good 2=Good 3=Medium 4=Bad 5=Worst
81.	How do you evaluate the role of NGOs in disseminating the technology?	1=Very good 2=Good 3=Medium 4=Bad 5=Worst
82.	How do you evaluate the role of the government in promoting the technology?	1=Very good 2=Good 3=Medium 4=Bad 5=Worst
83.	Does the technology bring any change in water colour?	1=Yes 0=No
84.	Does the technology bring any change in smell of water?	1=Yes 0=No
85.	Does the technology bring any change in the taste of water?	1=Yes 0=No
86.	Does the technology spread coldness?	1=Yes 0=No
87.	Do you have any physical reasons not to use and drink safe water?	1=Yes 0=No
88.	Do you have any psychological reasons not to use and drink safe water?	1=Yes 0=No
89.	Do you have any religious reasons not to use and drink safe water?	1=Yes 0=No

(A portion of this survey questionnaire has been used for understanding the regime dynamics of deep tube well)

Checklist for FGD and in-depth interview: Dynamics of social acceptability

1. Tell me your experience with drinking water and tube well technology.
2. Do you know about arsenic contamination in shallow hand pump tube well? How long are you living with arsenic?
3. Are you aware of drinking arsenic contaminated water? How would you assess the risk related to unsafe drinking water?
4. Tell me something about your water use practices (time spent, amount, distance etc.) before and after the arsenic crisis.
5. What are the alternatives you have to arsenic contaminate water and how did you get this technology?
6. To what extent is the technology and its spare-parts easily available during and after initial introduction?
7. Do you find any problem with using this technology?
8. Is this the technology that you can afford?
9. How would you assess the quality of water (colour, taste, temperature, freshness etc.) you are getting from the technology?
10. What are your reasons for accepting to use this technology?
11. Which technology do you prefer (for example, sono filter/deep tube well/improved dug well) and why?

Appendix B: Checklists for in-depth interviews and focus group discussions: Sono filter niche formation

General information about production and dissemination of Sono filter

1. Origin, development and manufacturing of Sono filter by Manob Saktu Unnyan Kendro (MSUK) and Sono Diagonstic Inc. (several models, number of Sono filters manufactured per year and sold)
2. Information about the buyers (how many Sono filters were bought by the organization and individuals also?)
3. Production oriented information (how many people are involved with production and dissemination activities of Sono filter in Manob Saktu Unnyan Kendro (MSUK)
4. Marketing of Sono filter (outlet, showroom, marketing network, repairing centres etc.)
5. Rate of manufacturing (number of Sono filters manufactured per day, capacity etc.)

Checklist for in-depth interview and Focus group discussions: Sono filter niche formation

Actor networks

1. Involvement of the actors in researching and developing prototype of Sono filoter.
2. Network of manufacturing, production, marketing and dissemination networks including individuals, donor agencies, government organizations, NGOs in various projects
3. Activities and degree of ties within each network

Expectations

4. Expectations of multiple actors (MSUK, scientist, policy makers, users, UP, DPHE, NGOs etc.) relating to production, availability, affordability, use, marketing, funding opportunities
5. Convergence and divergence of expectations: stagnation and future of Sono filter

Learning

6. First order learning: technical learning on prototype development, design improvement, quality of product, aesthetics, transportation and fragility issues, mode of dissemination
7. Second order learning: regularizing manufacturing, alternative marketing, repair, strategy of dissemination, further networking with GOs and NGOs, overcoming fund crisis, alternative investments, policy supports etc.
8. Planning of MSUK regarding the manufacturing and dissemination of Sono filter, involvement of local people, role of government and donors to overcome the stagnation

Appendix C: Checklists for in-depth interviews and focus group discussions: regime dynamics of deep tube well

1. General information:
History of arsenic mitigation in the area, number of safe and un-safe shallow tube well, number of deep tube well disseminated.

2. Hardware and software aspects of deep tube well
(Hardware of technology means the technical features e.g., design of the dug well and improved dug well, technology whereas software refers to the users' awareness and knowledge related to design of improved deep tube well. Try to get the historical trajectory of the technological design of deep tube well and users' journey with this till now.)

3. The user practice and application domain
(The user practice includes operation, maintenance, labour intensiveness, ability to fulfil drinking water demand, users' willingness to use and water use practice, how many times they use, who used and conditions of getting a deep tube well, how many deep tube well are functional now, how many households use a single deep tube well etc. Application domain explains the socio-economic contexts and market upon which the deep tube well is implemented, industry and market network)

4. Symbolic meaning of the improved dug well
(Symbolic meaning indicates normative properties of an innovation to users and other actors, beyond its performance and services: miracle technology, farm fresh water, purity) Local beliefs and culture about the deep tube well in relation to drinking water and arsenic contamination

5. Infrastructure
(Infrastructure means the organization, *its origin and activities, manufacturing, funding agencies, community organization, water users group, technicians, and retailers etc.* of associated activities related innovation and dissemination of deep tube well under arsenic mitigation project. How did DPHE and UP work, number of staffs, how many deep tube well did they disseminate through which projects, who installs deep tube well and repairing facilities, does the repairing work independently once after the project is over?)

5. Industry structure, policies and knowledge
(Industry structure explains the favoured terms in policies for promoting deep tube well through financing. Knowledge indicates the credibility of science underlying the safety issues related to innovation and dissemination of deep tube well.)

Appendix D: Survey questionnaire and checklists: Sociotechnical experiment with SAR

Survey Questionnaire

1.	Name of the respondent	
2.	Name of the household head	
3.	Year of education	
4.	Number of household members	
5.	Self-perceived socio-economic condition of the household	1=Always surplus 2= Sometimes surplus 3= Breakeven 4= Sometimes deficit 5= Always deficit
6.	Occupation of the household head	1= Farmer 2= Retired official 3- Shopkeeper 4=Businessman 5= Immigrant workers 6= Fisherman 7= Teacher 8= Others (Dairy milk producers, labourers, politicians etc.)
7.	Do you have a shallow tube well in your household?	1= Yes 0= No
8.	What is the status of your shallow tube well regarding arsenic contamination?	1= Yes 0= No 2= Not tested 3= Not known
9.	Amount of drinking water needed per day for your households	---------------- Liters
10.	Do you know the location where Sub-surface Arsenic Removal (SAR) is to be installed?	1= Yes 0= No
11.	How far the location is from your household?	-----------------Feet
12.	Are you willing to contribute for the installation of SAR?	1= Yes 0= No 2= Need to consult with family members
13.	In which field do you want to contribute?	1= Operation and maintenance (O & M) 2= Installation and O & M 3=
14.	How many times do you prefer to collect water in a day?	--------------times

15.	Which time do you prefer to collect water?	1= Morning 2= Afternoon 3= Morning and afternoon 4= Morning and night 5= Anytime when needed
16.	Who will collect drinking water for your family?	1= Woman 2= Man 3= Both

Checklists for in-depth interviews, focus groups, and consultation meetings: three functions of sociotechnical experiments

1. Could you please tell us about your drinking water practice and use?
   [Amount of drinking water used in the household per day, same or different source for all uses e.g., cooking, bathing, washing and cleaning, versus multiple sources for multiple uses, , ownership of water source, use of spot, issues relating to distance from water source, and household versus community scale of use etc.]
2. Could you please tell us your perceptions (and knowledge) about arsenic andiron in water supplies, and safe drinking water?
   [Level of awareness about drinking arsenic/iron free safe water, illness relating to arsenic contamination, risk perceptions, issues relating to taste, smell and colour of available water]
4. Do you have any idea about possible solutions for iron and arsenic removal from shallow tube well water? What is your priority to solve? If so, tell us about the options you know about and/or prefer and their merits and demerits; do you have any experience with technologies to remove iron and arsenic from water supplies? If so, who supported you and in what ways?
5. How do you see the primary design of SAR? Can you compare the reference technology and its attributes, with the design and functioning of SAR? Can you tell us about the characteristics of a desirable technology for removal of arsenic and iron, in your view? What are the attributes of safe drinking water?
6. Would you like to help us with implementing the experimental SAR technology?
   [Interest in participating in the implementation of the new technology, ability and means to do; current understanding of the technology and its operation and maintenance, etc.]
7. Are you interested to be involved with experimental Subsurface Iron Removal (SIR) technology as a way to implement a modified version of SAR?
   - Are people interested in connecting multiple hand pumps to one (community-scale) tank?
   - Are the materials such as tank, plastic pipe, electric pump, aeration plates, compressors, valve, generator or electricity etc. available in local markets and do you think these are costly?
   - What do you prefer, a family or community-scale injection and aeration facility?
   - Where will be a suitable position to set up the aeration tank (ground or above ground)?
   - What is the appropriate size of tank for certain volume/amount of water to be aerated?

- What will be the mechanism for mobilizing households and community?
- Are you willing to contribute to installation, operation and maintenance costs e.g., costs for electricity, technician's charge? What payment methods do you prefer: instalment, cash/kind etc.?
- Are you willing to spend time and money for injection and aeration?
- Do you see any problems and challenges with the aeration and injection mechanism, and coordination of aeration at community-scale?
- Who is willing to volunteer (i.e. be the caretaker family) to take responsibility for the operation and maintenance of the SAR experiment?
- What incentive structures are needed, in your view? What has worked in the past? *[Testing out the idea that community contributes up to 10% of the total installation cost and 100% of operation and maintenance cost. This implies combined ownership between community and implementing agency]*
- How can we develop an effective monitoring system; how can we ensure that technical support is available during and after installation?
- Is there any necessity to form a formal users group, how can we ensure involvement of relevant stakeholders like BRAC and DPHE at local level?
- How can we ensure participation of the community in design, construction and implementation of the experiment?

8. Could you please tell us your experience with experimental SAR and SIR? *[Preferences and limitations]*
9. Can you suggest ways in which we can test and improve the SAR design? Can you share your opinion on prototype, spot selection, social status and ownership?
10. Can you tell us about the security issues related with water collection from a community spot?
11. Issues with implementing experimental SAR:
    - What do you think about experimental SAR's contribution to arsenic and iron removal?
    - What do you think about an arsenic removal technology that can (also) improve colour, smell, and taste of water?
    - Are you willing to pay for removal of arsenic and iron from contaminated water?
    - What kind of technologies (shallow hand pump tube well based household filter, community water supply based on a large tank) do you prefer and why?
    - What do you think about using electricity to pump water for the large tank? [in terms of price, electricity usage etc.]
    - Please share your perceptions about the sub-surface arsenic removal (SAR) experiment: a. information about prototype and how to improve the design, b. perceived benefits, c. problems with SAR, d. cost, e. buying capacity, f. installation cost g. maintenance and operational costs, including electricity etc.
12. How can you be involved with this experiment?
    [Level of participation, engagement of rural people, inspiration, curiosity, ownership, ability and willingness to understand etc.]
13. How can we form a management committee? Can you share with us some ideas about an incentive structure through which the experimental SAR unit can be operated?
    [The role of management committee, distribution of activities, decision making, engaging others, solving problems etc.]

14. How would you evaluate the role of the management committee and their performance?
15. Do you have ideas about strategies for informing villagers, involving new users, engaging potential users and stakeholders, and monitoring formal and informal meetings?
16. Why didn’t you come to be involved in SAR experiments? Could you please state the reasons?
17. How would you evaluate the strategies used to raise interest and involve more people in SAR?
18. How do we ensure technical and financial support in the post-project period?
19. What are the conflicts around operation and maintenance of SAR? What are the conflicts between management committee and non-users?
20. Can you tell us about the social stratification and community relations, in relation to using the experimental spot?
21. Can you tell us about the reasons for the declining number of users of the experimental SAR unit, and why are the non-users are not coming to be involved?
22. Can you share your ideas about the formation of a community for implementing the experiment?
23. Can you evaluate the performance of SAR as an arsenic removal technology?
24. What do you expect from a technology like SAR? Could you suggest how we can move forward?
25. What in your view are the roles of the research team, the government and NGOs?
26. Do you understand the importance of the experiment as a way to develop a solution for arsenic crisis?
27. Do you think researcher’s needs and people’s needs are different, and that public needs cannot be compatible with scientific requirements?
28. Did the lack of success of arsenic mitigation technologies make you more frustrated and hesitant to be involved with a new experiment?
29. How can we overcome the social and management conflicts that restrict the success of a technology?
30. What should be the strategies to operate SAR in the post-project period?

Appendix E: List of respondents

Name and detail information	Date and Place
Beauty Khatun	December 21, 2011 Boro Dhulundi, Ghior, Manikganj
Munnu Sheikh	December 20, 2011 Dorikandi, Arua, Shibaloya, Manikganj
FGD with female beneficiaries No. of participants:10	December 23, 2011 Shimulia Ghior, Manikganj
FGD with male beneficiaries No. of participants:10	December 24, 2011 Pukhuria, Ghior, Manikganj
FGD with female beneficiaries No. of participants:10	December 25, 2011 Pukhuria, Ghior, Manikganj
Mst. Banu Khatun	December 10, 2011 Uttar Bhabanipur, Dharampur, Bheramara, Kushtia
Mst. Shorifa Khatun	December 10, 2011 Uttar Bhabanipur, Dharampur, Bheramara, Kushtia
Liakat Ali	December 11, 2011 Ramachandrapur, Dharampur, Bheramara, Kushtia
Shukila Begum	December 12, 2011 Uttar Bhabanipur, Dharampur, Bheramara, Kushtia
Zahurul Islam	December 13, 2011 Uttar Bhabanipur, Dharampur, Bheramara, Kushtia
Rupali Begum	December 14, 2011 Nawda Khemirdiyar, Bheramara, Kushtia
Raima Begum	December 14, 2011 Nawda Khemirdiyar, Bheramara, Kushtia
FGD with female beneficiaries No. of participants:10	November 17, 2011 Nawda Khemirdiyar, Bheramara, Kushtia
FGD with male beneficiaries No. of participants:10	November 17, 2011 Dakkhin Bhabanipur, Bheramara, Kushtia
FGD with female users No. of participants:10	November 18, 2011 Nawda Khemirdiyar, Bheramara, Kushtia

Caretaker of SIDKO Akhaz Hafez Md. Rustom Ali	January 7, 2012 Suchipara, Sharasti, Chandpur
Ibrahim Patuari	January 8, 2012 Suchipara, Sharasti, Chandpur
Rohima Begum	January 8, 2012 Suchipara, Sharasti, Chandpur
FGD with male beneficiary Participants: 10	January 9, 2012 Suchipara, Sharasti, Chandpur
FGD with female beneficiary Participants: 10	January 10, 2012 Suchipara, Sharasti, Chandpur
FGD with female beneficiary Participants: 10	January 11, 2012 Doikamta, Sharasti, Chandpur
Sudhir Kumar Ghose Superintend Engineer Ground Water Circle, DPHE	December 28, 2011 DPHE head office, Kakrail, Dhaka
Dr. A.K. Munir Co-inovetor of SONO filter & Chairman of MSUK	December 10, 2011 MSUK head office, Courtpara, Kushtia
Mr. Obaidur Rahman Sub-assistant engineer, Bheramar, Kushtia	December 13, 2011 DPHE office, Bheramara, Kushtia
Habibur Rahman UP Chairman, Suchipara Union, Sharasti, Chandpur	January 9, 2012 Union Parishad Complex, Suchipara, Sharasti, Chandpur
Bijon Kumar Sarkar Director, SEDA, Pukhuria, Ghior, Manikganj	February 11, 2012 September 13, 2013 Pukhuria, Ghior, Manikganj
Mrs. Sarker Chairman, SEDA	February 11, 2012 Pukhuria, Ghior, Manikganj
Shah Abdul Awal Coordinator, MSUK, Kushtia	December 9, 2011 December 12, 2012 MSUK Head office, Kushtia
Lutfar Rahman, regional manager, NGO forum	August 13, 2014
Mahfuzur Rahman, regional manager, NGO forum	August 16, 2014
Shahida Begum, MSU, DPHE	January 13, 2013
Local workshop in Shahrasti Upazilla Chairman, Sharasti	Upazila Parishad December 24’ 2012
Local Workshop in Bheramera	January 11, 2012 Mokarimpur Union, Bheramera, Kustia
Mr. Obaidur Rahman Sub-assistant engineer, Bheramar, Kushtia	December 13, 2011 DPHE office, Bheramara, Kushtia
Habibur Rahman UP Chairman, Suchipara Union, Sharasti, Chandpur	January 9, 2012 Union Parishad Complex, Suchipara, Sharasti, Chandpur
Bijon Kumar Sarkar	Fabruary 12, 2012

Director, SEDA, Pukhuria, Ghior, Manikganj	Pukhuria, Ghior, Manikganj
Abdul Awal Coordinator, MSUK, Kushtia	December 9, 2011 MSUK Head office, Kushtia
Hemayet Hossain, BCSIR	January 28, 2012, Dhaka
Mahfuzur Rahman, Manger BRAC WASH	March 20, 2013. Sharasti, Chandpur
SM Ihtashemul Hoque Consultant, JICA	August 18, 2013
Avizit Reaz Quazi Consultant, PSU	July 25, 2013 January 31, 2013
Md. Mohsin PSU, DPHE	July 30, 2013
Md. Alauddin Ahamed WHO, WASH Consultant	July 31, 2013
Peter Ravenscroft UNICEF, Consultant	April 10, 2013
Kazi Matin U Ahmed Dhaka University Scientist	March 09, 2014
ABM Borhan Bodruzzaman BUET Scientist	March 12, 2014
Saifur Rahman Executive engineer, DPHE	August 18, 2013 September 18, 2014
S M Shahidullah NGO Forum Senior Chemist , Water Quality Testing Laboratory, Environment & Water Quality Management Cell	March 20, 2013 Dhaka
Hemayet Hosaain BCSIR, Scientist	January 19, 2012 Dhaka
AKM Munir MSUK, Scientist	December 20, 2012 December 18, 2013 Kushtia
Hasin Jahan Water Aid Bangladesh Development expert	January 19, 2014 Dhaka
Sandra B. Freitas TU Delft, Scientist	May 23, 2015 e-mail communication
Dr. Linda Smith Filters for Famailies	March 26, 2015 e-mail communication
Dr. Abul Hussam George Meson University	Personal communication, April 28, 2015
Syed Borhan Kabir Poripprkkhit Media expert	Personal communication January 14 , 2015
Mohammed Moshiur Rahman TU Delft, Scientist	Personal communication December17, 2014
Zahid Hasan VU Amsterdam, Scientist	Personal communication December 10, 2014
Md. Mojahudul Islam EAWAG, Scientist	Personal communication April 6, 2015
Shamsunnahar, Housewife	December 17, 2013, Payob, Comilla
Milon, Housewife	December 17, 2013, Payob, Comilla

Abdul Malek, Retired teacher	December 18, 2013, Payob, Comilla
Rozina Akter ,Housewife	December 18, 2013, Payob, Comilla
Shahjahan Mia, NRB	December 20, 2013, Payob, Comilla
Abdus Salam, Marginal farmer	December 21, 2013, Payob, Comilla
Shirina Aktar ,Housewife	December 20, 2013, Payob, Comilla
Monir Hossain, Sharecropper	December 20, 2013, Payob, Comilla
Md. Mohibullah ,Principal	December 20, 2013, Payob, Comilla
Shahalam ,UP Member, Business	December 21, 2013, Payob, Comilla
Md. Fazlul Hoque ,Retired army	December 23, 2013, Payob, Comilla
Mr. Ripon, Shop keeper	December 20, 2013, Payob, Comilla
Abu Bakar, Small businessman	December 20, 2013, Payob, Comilla
Badal, Small farmer	December 20, 2013, Payob, Comilla
Golam Mostofa, Farmer	December 17, 2013, Payob, Comilla
Parvez Hasan ,Non Resident Bangladeshi	December 17, 2013, Payob, Comilla
Diwara Begum, Housewife	December 17, 2013, Payob, Comilla
Md. Abdul Latif ,Farmer	December 18, 2013, Payob, Comilla
Mst. Sumi Khatun, Housewife	December 21, 2013, Payob, Comilla
Mst. Zesmin Akter ,Housewife	December 20, 2013, Payob, Comilla
Sabeka Khatun, Housewife	December 18, 2013, Payob, Comilla
Mst. Bilkis Begum, Housewife	December 18, 2013, Payob, Comilla
Halima Begum, Housewife	December 18, 2013, Payob, Comilla
Mst. Parveen Akhter, Housewife	December 18, 2013, Payob, Comilla
Morsheda Begum, Housewife	December 18, 2013, Payob, Comilla
Md. Aabdul awal ,Farmer	December 17, 2013, Payob, Comilla
Abdur Rahman ,Retired officer	December 19, 2013, Payob, Comilla
Bayezid Hasan, Farmer	December 22, 2013, Payob, Comilla
Masum Ahmed ,Farmer	December 22, 2013, Payob, Comilla
Shah Oliul Gani, Religious leader	December 18, 2013, Payob, Comilla
Monir ,School staff, Payob	December 18, 2013, Payob, Comilla
Renu Mia, Retired labour	December 18, 2013, Payob, Comilla
Raja Mia, Farmer	December 18, 2013, Payob, Comilla
Md. Shaheed Mia, Small business	December 18, 2013, Payob, Comilla
Abul Hasem Farmer	December 20, 2013, Payob, Comilla
Rasel, Student	December 20, 2013, Payob, Comilla
Momena, Housewife	December 20, 2013, Payob, Comilla
Ferdousi Begum ,Housewife	December 20, 2013, Payob, Comilla
Badal, Farmer	December 21, 2013, Payob, Comilla
Ali Ahsan, Teacher (Madrasa)	December 21, 2013, Payob, Comilla
Mafia Akter, Housewife	December 21, 2013, Payob, Comilla
Rofeza Begum, Housewife	December 22, 2013, Payob, Comilla
Hasina Begum, Housewife	December 22, 2013, Payob, Comilla
Ayesha Parvin, Housewife	December 22, 2013, Payob, Comilla
Nazma Akter ,Housewife	December 22, 2013, Payob, Comilla
Amir Hossain ,Farmer	December 18, 2013, Payob, Comilla

FGD with 7 participants	July 07, 2014 Pukhuria, Baliakhora, Ghior, Maanikganj
FGD with 10 participants	July 07, 2014 Pukhuria, Baliakhora, Ghior, Manikganj
FGD with 9 participants	July 5, 2014 BibiRashti, Baliakhora, Ghior, Manikganj
FGD with 8 participants	July 5, 2014 BibiRashti , Baliakhora , Ghior, Manikganj
Tamiz Uddin Ex government official, caretaker of SAR	August 29, 2014 Bangala, Singair Manikganj
Shahinur Rahman Tailor	October 08, 2014 Bangala, Singair Manikganj
Fazlul Haque Owner of tea stall	August 28, 2014 Bangala, Singair Manikganj
Dhirendra Kumar Sarker Farmer, former user, not using during the time of interview	August 28, 2014 Bangala, Singair Manikganj
Suvash Chandra Mandal Management committee, Farmer, used occasionally, but not now	August 28, 2014 Bangala, Singair Manikanj
Ananda Mandal Farmer, used occasionally, but not now	August 29, 2014 Bangala, Singair Manikganj
Tazim Uddin Farmer, once they used, but not now	August 27, 2014 Bangala, Singair Manikganj
Izzot Ali Management committee, Farmer, once they used, but not now	August 30, 2014 Bangala, Singair Manikganj
Uttam Ghosh Shop keeper, previously used, 1000 feet distant	August 30, 2014 Bangala, Singair Manikganj
Harun Rajbangshi, businessman	August 30, 2014 Bangala,Singair Manikganj
Lota Rani Mondol Management committee Housewife	August 30, 2014 Bangala, Singair Manikganj
Asma Akhter Management committee, housewife	August 29, 2014 Bangala, Singair Manikganj
Sayed Joynul Abedin Assistant General Manager, Pran-RFL Group	Janauary 23, 2014 January 16, 2015 Dhaka
Kazi Mafiz Field Officer Rupantor	December 11, 2014

Nur Islam Head of Human Resources Jagoroni Chakkro Foundation	December 21, 2014
Plaban Ganguly Field Coordinator World Vision Bangladesh	December 1, 2015
Shafiqul Alam HR of Arsenic Department	December 8, 2014
Saifuzzaman Khan Field Officer Nijera Kori	December 8, 2014
Rakib Uddin Field Officer, Sushilon	December 10, 2014

Summary

Problem statement

Although there has been considerable progress in providing pathogen-safe drinking water, including in the developing world, contamination of groundwater by naturally occurring arsenic is now recognised as a severe environmental and health disaster. This is a serious challenge in rural Bangladesh as well. The provisioning of safe drinking water through development of arsenic mitigation technologies remains a socially and technically complex and expensive task. With an effort of two decades, two categories of arsenic mitigation technologies have been developed and introduced in Bangladesh: first, arsenic removal technologies that purify arsenic-contaminated shallow tube well water and alternatives to the shallow-tube well. However, no single arsenic mitigation technology has been widely taken up, particularly one that is suitable for all affected areas. Besides, a wide range of arsenic mitigation technologies and/or safe drinking water options face challenges of social acceptability and widespread dissemination. This generates a complex socio-technical challenge of how to provide safe drinking water to the rural population of Bangladesh, requiring input from both technical and social sciences.

Research objectives and questions

This thesis analyses socio-technical changes in the safe drinking water regime in rural Bangladesh, following the discovery of arsenic contamination of shallow tube well drinking water. It analyses experiences and ongoing experiments with various arsenic mitigation technologies that seek to re-stabilize the drinking water sector of rural Bangladesh in the post-arsenic contamination phase. In doing so, it goes beyond a dominant focus on expert views on “social acceptability” of various technological options, by exploring the user perspective on social acceptability as well. Furthermore, social acceptability of given technological interventions in only one piece of the larger puzzle of tackling the safe drinking water provision challenge. It is important to also analyse why a specific technological innovation becomes dominant, and when and how certain innovations start to occupy a technological niche from which they can be scaled up. In addressing these aspects as well, the thesis embeds a user-oriented analysis of social acceptability into a broader study that explores the dynamics of socio-technological change, using an analytical lens drawing on transition theory. In particular, it draws on the Multilevel Perspective in transition theory, which considers interlinkages between the landscape, regime, and niche levels, in theorizing the dynamics of sociotechnical transformations. It applies a conceptual framework deriving from transition theory to analysing the dynamics of disruption and re-stabilization of the safe drinking water regime in a developing country context. The overarching research objective is to understand the factors shaping the success and failure of socio-technical changes to the safe drinking water sector in rural Bangladesh in the post-arsenic contamination phase.

The four sub-research questions to address this research objective are:

1. How do users understand social acceptability of three diverse arsenic mitigation technologies (deep tube well, improved dug well and Sono filter) in use in rural Bangladesh?
2. How and why does a technological innovation (the deep tube well) deployed to provide safe drinking water become dominant in the context of arsenic contamination?
3. Why did the promising take-off of the household arsenic removal Sono filter technology stagnate and fail to establish itself as a niche technology?
4. How do novel experimental technologies (such as the Sub-Surface Arsenic Removal) function as emerging socio-technical experiments in rural Bangladesh, and (how) can they re-stabilize the safe drinking water regime?

Methods, analysis and findings

Using a case study methodology and qualitative methods of data generation such as surveys, semi-structured interviews, focus group discussions and primary document analysis, this thesis addresses the research questions in three steps (Chapters 2-4). Chapter 2 undertakes a *user-oriented analysis* of social acceptability of arsenic safe technologies in rural Bangladesh. It discusses how multiple technological interventions seeking to ameliorate the problem of arsenic contamination face hurdles in securing social acceptance, i.e. a willingness of users to receive and use a technology. While most existing literature has focused on expert understandings of social acceptability, this chapter analyses how users understand the factors shaping social acceptability of safe drinking water options in rural Bangladesh. It then deploys such understandings to comparatively assess which factors users see as most important in securing social acceptance of three safe drinking water options in rural Bangladesh: the arsenic removal household (Sono) filter; the deep tube well, and improved dug well. The chapter draws on focus groups and semi-structured interviews with technology users in six villages across three districts to analyze how users assess the social acceptability of specific arsenic safe technologies. The findings highlight that factors such as availability, affordability and compatibility with existing water use practices, as understood by users, are key to securing their acceptance of a specific arsenic safe option. In concluding, this chapter points to a future research agenda in analyzing user-oriented social acceptability of arsenic safe technologies in developing country contexts.

Chapter 3 explains why and how the deep tube well as a safe drinking water technology has become dominant in mitigating the arsenic crisis in rural Bangladesh. This chapter applies insights from the Multi-Level Perspective on transitions in explaining changes to the socio-technical safe drinking water regime in rural Bangladesh. Data about seven dimensions of regime change was gathered from key actors, through in-depth interviews, focus groups sessions, a survey and a workshop. The findings reveal that with the introduction of deep tube well as an arsenic mitigation technology, changes in the seven dimensions helped to transform the existing safe drinking water regime in order to re-stabilize it. Technological attributes, symbolic meaning, industry structures, and techno-scientific knowledge supported an evolving dominance of the deep tube well. Besides, user practices as well as related infrastructures adapted to the use of deep tube wells, and new policies stimulated its application. The analysis in this chapter reveals that the dimensions of technological change in the existing regime are consistent with the features of incremental innovation. It also documents the relevance of the Multi-Level Perspective on transitions to analysing socio-technical innovation in a developing world context.

Chapter 4 explores how arsenic contamination of shallow hand pump tube well drinking water in Bangladesh has created opportunities for radical innovations to emerge. One such innovation is the household Sono filter designed to remove arsenic from water supplies. Applying a strategic niche management approach, and based on interviews, focus groups and a workshop, this chapter explained the Sono filter's failure to establish itself as a successful niche technology. Three explanatory factors are identified: lack of a strong social network (of technology producers, donors, users, and government actors) around it; diverging expectations regarding its potential to be a long-term solution; and lack of second order learning amongst key actors. This chapter also highlights how the overwhelming dependence on externally funded arsenic mitigation projects deters successful niche formation of radical innovations in the context of the developing world.

Chapter 5 analyzes experiments in rural Bangladesh with a recent arsenic mitigation innovation, so-called Subsurface Arsenic Removal (SAR), a technique designed to secure in-situ removal of naturally occurring arsenic in groundwater. SAR operations involve aeration of extracted groundwater from shallow hand-pump tube wells, and re-injection into the aquifer. Subsequent extraction can remove both arsenic and iron from groundwater through in-situ processes of oxidation, adsorption, and co-precipitation in the subsurface. This new technology was deployed on an experimental basis in two sites in rural Bangladesh. This chapter assesses whether and to what extent these first field experiments with SAR can be conceptualized as "socio-technical experiments" designed to incubate and improve radical technological innovations by serving as 'living lab", "window" and/or "agent of change". As per writings in transition theory, an experiment functions as a living lab if it permits testing, learning and improving upon a technological innovation. It functions as a window if it is able to facilitate communication and conversation by raising actors' interest and enrolling new actors. It functions as an agent of change if it can successfully stimulate changes in potential users' practices and behaviours. Through studying two SAR experiments, this chapter shows that this novel technology served as a living lab and window, but not (yet) as agent of change, partly because integrating social considerations (such as community buy-in, appropriate site selection and post-installation support) into SAR prototype design during field experimentation proved very difficult. A key obstacle was that the technical efficacy of the technology remained a primary concern during experimentation, and it was unsafe to make water deriving from experimental SAR units available to users. The technology thus remained an abstract idea and provided unable to stimulate behavioral changes amongst users.

Conclusions and contributions

Overall this thesis has shown that technological innovations that are seen as more socially acceptable by users acquire dominance in a re-stabilized sociotechnical regime (as is the case with the deep tube well technology). Furthermore, radical technological innovations, such as household arsenic removal filters, which are still at the niche (or pre-niche) experimental stage often struggle to establish themselves and scale up, with one reason being the lack of prospects to secure user social acceptability at these early stages. The findings of the thesis also shed light on the applicability in developing country contexts of certain concepts in transition theory, including strategic niche management of technological innovations, and the multilevel perspective shaping sociotechnical transformations. One key finding is that niche formation for radical innovations cannot succeed in contexts where a hybrid set of actors involved in a sociotechnical regime prioritize and promote incremental innovations. This thesis thus highlights the need to focus attention on what can be referred to as “pre-niche” activities in experimenting with radical technologies, including at the incubation phase. This can help to shed light on conditions under which real world experiments with radical innovations *can* serve as agents of change to facilitate sustainable uptake of arsenic safe technologies, particularly in rural developing country contexts. The thesis findings nonetheless reinforce the importance of incremental innovations in mitigating the arsenic contamination challenge in rural Bangladesh, also because of the limitations associated with dependence on external funding for experimenting with more radical innovations. These general findings have implications for the successful implementation of arsenic mitigation policies, and sustainable experimentation and uptake of safe drinking water innovations in rural Bangladesh, even as they provide input into the relevance of a transition theory lens into sociotechnical transformations in a developing country context.

Acknowledgements

I am defending my doctoral thesis in 2018, the year of the centenary of Wageningen University. It makes me very proud that one of the most significant events of my life coincides with such an auspicious occasion for my institution. Looking back on the process of conducting this PhD research, I am afraid that I may not be able to do justice to all those to whom I am so indebted for their immense help and support along the way. It was not entirely a smooth path, since I underwent many difficult situations. Without the cooperation and encouragement of many, I would not have been able to complete this journey. I do not have words enough to thank them.

First and foremost, I express my heartiest thanks and respect to my daily supervisor and co-promotor Dr. Aarti Gupta, whose serious guidance, engagement, and supervision in every step of the research – from idea generation, to theoretical underpinning, and chapter writing – led the way. I have learned a lot from her. To me, she remains a perfect example of how passionate an academic can be. I also extend my sincere gratitude to my promotor Professor Arthur P.J. Mol, who can comment on an iceberg by seeing only its tip. Despite his busy schedule, Arthur has always provoked me to think more about my research. I am grateful for his patience and prudent suggestions. I am also very grateful to my local supervisor in Bangladesh, Professor Mahbuba Nasreen, for proposing my name for this doctoral project, and for extending all possible support during my fieldwork. I thank my ENP colleagues for their cooperation, particularly Corry Rothuizen for her extraordinary support during my ENP stay, and for all her guidance that made administrative tasks easier.

I would like to thank all of my co-authors, namely Bas van Vliet, Doris van Halem, and Mohammed Mashiur Rahman for discussions and contributions to my published papers, with particular gratitude to Bas van Vliet for theoretical contributions. I am grateful to all article reviewers for constructive feedback on initial versions of my articles. I especially thank Sautrik Basu from India, with whom I spent a considerable amount of time discussing various issues in the Leeuwenborch, which enhanced my understanding of many theoretical aspects of sociology.

I would like to acknowledge the funding agency NWO-WOTRO for financial support of my dissertation project. In this connection, I convey my gratitude to the supervisors of the NWO-WOTRO SAR team, in particular, to the late Wilfred FM Roling, and to Doris van Halem, Jasper Verberk, Mark Bakker, Kazi Matin Uddin Ahmed, Sirajul Islam Khan and Mahbuba Nasreen. I would also like to thank the other doctoral researchers, Sandra Borges Freitas and Zahid Hassan. I am particularly thankful to Mohammed Moshiur Rahman for all his support and inspiration, both academic and non-academic, during my research in Bangladesh and the Netherlands.

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While doing the PhD, I got the opportunity to participate in workshops at the STEPS summer school (IDS, Sussex University) and present papers in conferences in Ethiopia and USA, where I got new ideas and met many academics, students and researchers from different countries. These experiences were very important to me during my PhD. At the same time, I also frequently visited many different European museums, including particularly the Van Gogh Museum in Amsterdam, which opened up a universe of unique creations and visions that inspired me to also seek to leave a stamp.

Above all, it would barely be possible to complete this journey, dealing with the ups and downs along the way, without the cooperation and support of my wonderful wife Doli Pal. She sacrificed a lot particularly when I was in the Netherlands, as she had to manage family affairs alone while continuing with her own academic career. I would also like to thank our only son Kunjo Kalarov Pi for always being a source of joy and inspiration. I am further indebted to my parents, Rekha Kundu and Kalidas Kundu, for their continuous support and good wishes for my success. I also thank my sister, Rima Dey, my in-laws, Kalpona Paul and Madhushudon Paul, and my brother-in-law, Nirmal Dey, and Niloy, Nakshatra and Sagor, among other family members and relatives, for their support during this process. It is also necessary to mention that I underwent three critical surgeries during the last couple of years of my PhD work, giving rise to serious uncertainty regarding the fate of my PhD. The patience and cooperation that my family and supervisor had for me in these situations are unforgettable. They not only took care of me, but also gave me courage to overcome all difficulties.

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Wageningen/ Dhaka

12 March 2018

About the Author

Debasish Kumar Kundu was born in Pabna, Bangladesh, on 5 September 1980. Debasish obtained his Bachelor's degree (BSS) and Master's degree (MSS) in Sociology from the Department of Sociology at the University of Dhaka, Bangladesh. For the outstanding result he obtained in his MSS, he was awarded the prestigious A.K Nazmul Karim Memorial Gold Medal. After completing his Master's degree, Debasish joined the Bangladesh Rural Advancement Committee (BRAC) Research and Evaluation Division as a senior research associate. In 2008, Debasish joined the teaching staff of the Department of Sociology of Jagannath University in Dhaka, Bangladesh. Since 2011, Debasish has taught in the Department of Sociology of the University of Dhaka, Bangladesh. His keen academic interests cover sociological theories, environmental sociology and sociology of science and technology. Apart from academics, Debasish is interested in literature, politics, music and cinema. He is also passionate about creative writing.

Photo credit: Mofazzal Hossain sumon

Training and Supervision Plan

Debasish Kumar Kundu

Completed Training and Supervision Plan

Wageningen School of Social Sciences (WASS)

Name of the learning activity	Department/Institute	Year	ECTS*
A) Project related competences			
Political Theory (ENP 35306)	WUR	2010	6
"Dynamics of social acceptability of arsenic mitigation technologies in Rural Bangladesh: Lessons from three technologies"	EAWAG, International conferences GeoGen, Ethiopia	2013	2
Steps summer school, Institute of Development Studies, Sussex University	IDS	2013	6
B) General research related competences			
WASS Introduction course	WASS	2013	1
Qualitative Data Analysis: Procedures and Strategies (YRM 60806)	WUR	2010	6
Research Methodology I: From Topic to Proposal	WASS	2011	4
Writing ethnographic and other qualitative - interpretive research: An inductive learning approach	WASS	2012	3
Systematic approaches to reviewing literature	WASS	2014	4
C) Career related competences/personal development			
Information Literacy and End notes	WGS	2011	0.6
Techniques for Writing and Presenting a Scientific Paper	WGS	2013	1.2
Writing of the PhD research proposal	WUR	2011	6
Total			39.8

*One credit according to ECTS is on average equivalent to 28 hours of study load

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