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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.

Keywords: Arsenic mitigation; Bangladesh; Safe drinking water; Sono filter; Strategic niche management; Technological innovation

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% to 72%

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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 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, it has even 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 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 3 introduces the research methods used, followed by the analysis of experimentation with the Sono filter in specific districts in rural Bangladesh (Section 4). Section 5 explains the process of niche formation and stagnation, followed by discussion and conclusion (Section 6).

2. Conceptualizing niche formation

In theoretical terms, four frameworks could have been used to analyze the promise of the Sono filter as a radical innovation in arsenic mitigation in rural Bangladesh. These include transition management, technological innovation system, MLP and SNM (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 MLP and 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 socio-technical 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, 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 (that is, innovation) in order to fulfill 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 1).

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 fulfill 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

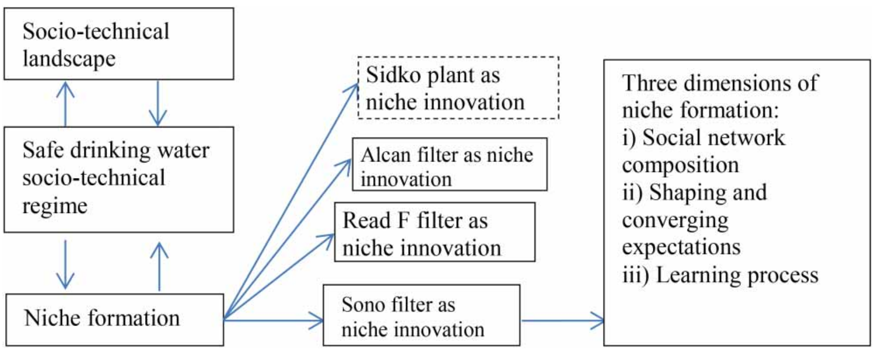

Fig. 1. Conceptualizing three dimensions of Sono filter niche formation.

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 Bangladeshis 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).

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 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

Table 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 LGIs
	4 with DPHE engineers as mandated state agency for arsenic mitigation
Focus group sessions	*Hybrid actors:*
	3 focus group sessions with 30 Sono filter users
Workshop	15 niche and hybrid actors including MSUK, other NGOs, DPHE, LGIs, community representatives and users

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 facto 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, NGOs, international donors and governmental organizations).

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 thirty-nine 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 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 (for example, disposal of sludge), interaction with donors and implementing NGOs and governmental organizations, 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 the Sono 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. 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% of the rural population, a huge public health success for Bangladesh (Flanagan *et al*., 2012). The National Water Act of Bangladesh highly favored the installation of shallow hand pump tube wells to provide safe drinking water in rural areas, as did many other water policies (Government of Bangladesh, 2013). In addition, an adequate industry structure that included 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.

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 Kushtia Sono Diagnostic Centre. After several design modifications, Sono two-bucket filter (Sono 45–25 model) was developed in 2003 (Figure 2). This filter won the 2007 United States National Academy of Engineering Grainger Challenge Prize for sustainability, which brought national and international attention to 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 L of clean water per hour and its guaranteed life span is 5 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 2). This

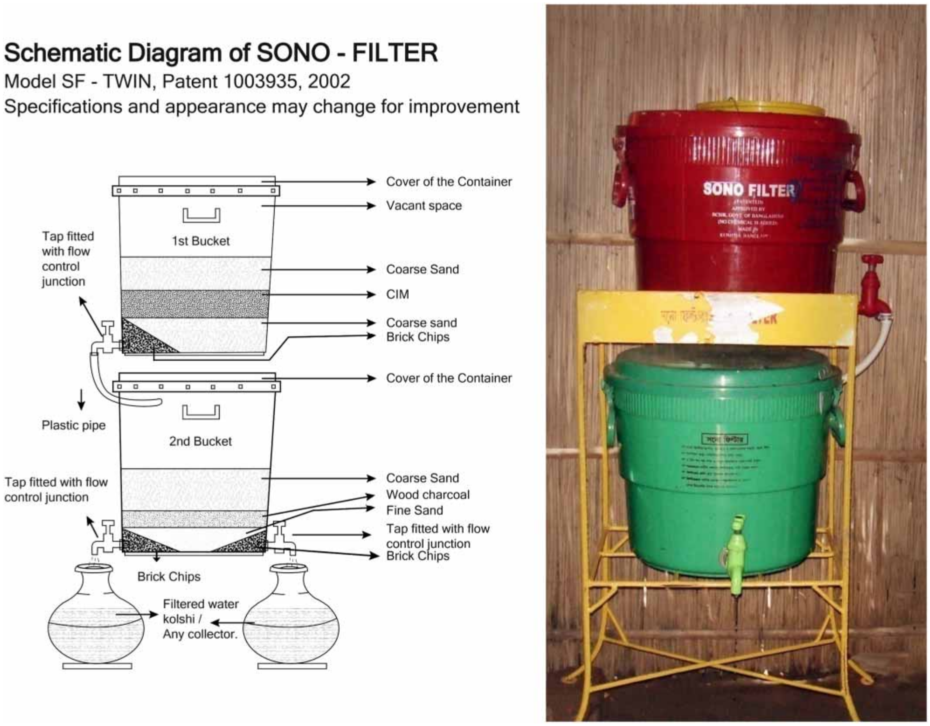

Fig. 2. Schematic diagram of Sono 2-bucket filter (Hussam *et al.*, 2008) (left); picture of Sono filter taken by one of the authors (right).

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, 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, 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 3). Information by MSUK showed that institutional buyers (mainly NGOs, often using donor funds) procured around 73% of the totally manufactured filters until 2014, of which MSUK itself bought around 29% through its donor-funded projects (Figure 4)[1].

[1] 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).

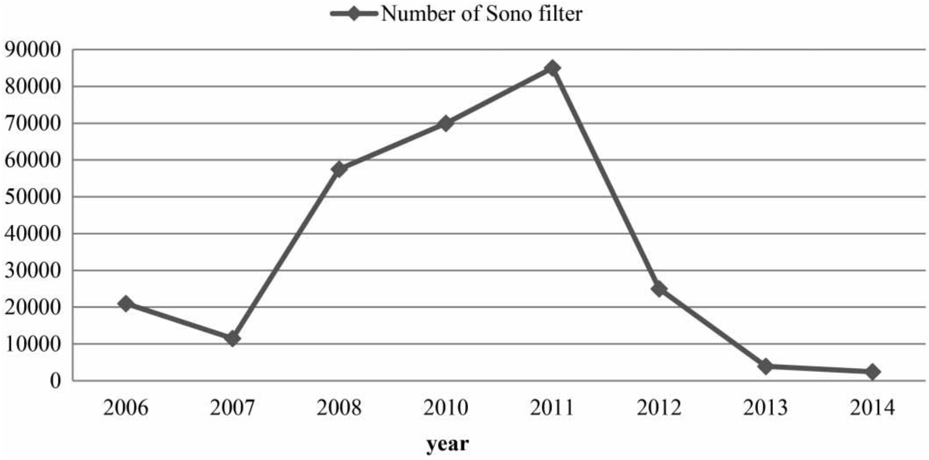

Fig. 3. Yearly manufacturing of Sono filters.

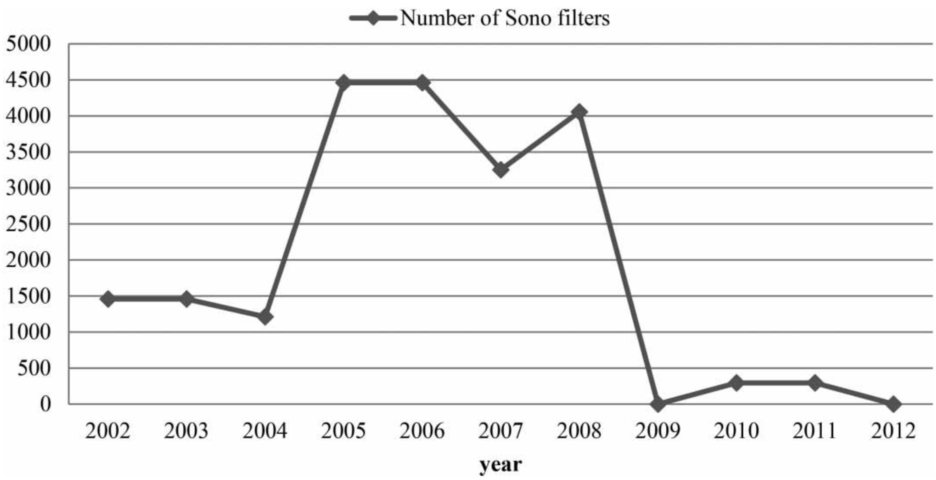

Fig. 4. Year-wise average dissemination of Sono filter only by MSUK with support from donor agencies.

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-up 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 eighteen out of the sixty-one arsenic contaminated districts) (DPHE & JICA, 2009)[2]. Second, the production and dissemination of the Sono filter was irregular, with large

[2] 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.

discontinuities (Figures 3 and 4). Third, most disseminated filters were abandoned before reaching their guaranteed life time of 5 years and were not replaced by new filters (Kabir & Howard, 2007)[3–5].

5. Analyzing stagnation in niche formation

In analyzing 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 2).

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

Table 2. Sono filter niche formation.

	Dimensions of niche formation		
Time period	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

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[3] For example, only three out of 100 Sono filters distributed in some Bangladeshi villages were still in use 2 years after they were acquired. Accessed from: www.echoinggreen.org/fellows/minhaj-chowdhury; accessed on: December 13, 2014.

[4] Figure 3 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 and Hussam *et al.* (2008).

[5] Figure 4. Donor agencies: Die LichtBrucke (DLB) of Germany, Good Gift Catalogue (GGC) of United Kingdom and the Federal Ministry of Economic Cooperation and Development, Germany.

run by family members of the inventors, such as Sono Diagnostic Centre, Human Development Research Centre, Quashem-Nahar Trust Fund), but this network succeeded in supporting early research and development activities (Table 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 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 twenty-seven staff, MSUK had the capacity to (manually) produce 200 filters per day in an 8 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.

Besides a very limited number of individual buyers, three kinds of institutional buyers articulated demand, according to MSUK. These included: (i) seventeen NGOs (including many partner NGOs who worked in collaboration with national NGOs) bought filters with international donor support[6]; (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)[7]. 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 a 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 (for example DPHE and UNICEF) discontinued their role in Sono filter niche formation. Similarly, many crucial NGOs (for example 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 (for example Bangladesh Rural Advancement

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[6] Including 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.

[7] 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 2,300 filters were imported from Bangladesh until 2014.

Committee (BRAC), Jagoroni Chakro Foundation, Rupantor, Nijera Kori, Dipsetu and World Vision) noticed that MSUK never contacted them and lost interest in promoting the filter. Overall, interviews with eleven implementing NGOs confirmed that MSUK never asked for feedback for further development of the 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 the 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 1,400 out of 2,000 filters disseminated in Mokarimpur union of Kushtia district since 2005 remained functional after 7 years, whereas DPHE and local governmental agencies estimated this to be fewer than 100 filters.

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.

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 policymaker 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.*, 2016). 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 2 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, p. 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 the 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, 1,500, 60 and 210 filters respectively 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 BRAC, which had large water and sanitation programs 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)[8], 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 5, 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 centers elsewhere in the country, except for a small display point in Dhaka[9], 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.

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.

[8] The amount is equivalent to 25% of the annual development budget of Bangladesh (Barkat & Hussam, 2008).
[9] Human Development Resource Centre, a Dhaka based non-governmental research organization, headed by inventor's brother.

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. Third, 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 the 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 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 (for example, 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 the filter and its services. MSUK and other NGOs developed no strategy to empower vulnerable people at risk to lobby the government and donors for a 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.

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's 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 the 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 the 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, the priority of mitigating arsenic crisis had 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) 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.*, 2016). 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 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.

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References

Adams, P. (2013). In Bangladesh, funds dry up for arsenic mitigation research. *The Lancet 382*(9906), 1693–1694.

Adel, M. M. & Hossain, M. (2008). Sono filter waste disposals contradict safe environmental regulations. In: *International Conference on Water Scarcity, Global Changes, and Ground Water Management Responses*. Fried, J. & Scherfig, J. (eds). University of California, Irvine, USA.

Ahmed, F. (2002). *Arsenic Mitigation in Bangladesh*. ITN-Bangladesh, Dhaka.

Ahmed, K. M. & Ravenscroft, P. (2009). *Sector Development Plan (FY2011–25): Water Supply and Sanitation Sector in Bangladesh. Working Document Number 4: Recommendations for Revised Implementation Plan for Arsenic Mitigation*, Government of Bangladesh: Local Government Division, Policy Support Unit.

Ahmed, M. F., Ahuja, S., Alauddin, M., Hug, S. J., Lloyd, J. R., Pfaff, A., Pichler, T., Saltikov, C., Stute, M. & van Geen, A. (2006). Ensuring safe drinking water in Bangladesh. *Science 314*(5806), 1687–1688.

Barkat, A. & Hussam, A. (2008). Provisioning of arsenic-free water in Bangladesh: A human rights challenge. *Engineering, Social Justice, and Sustainable Community Development,* Organized by the National Academy of Engineering (NAE) Centre for Engineering, Ethics, and Society (co-sponsored by the Association for Practical and Professional Ethics, and the National Science Foundation), Washington, DC, October 2–3, 2008.

Biswas, A. K. & Tortajada, C. (2010). Future water governance: problems and perspectives. *International Journal of Water Resources Development 26*(2), 129–139.

Black, M. (1990). *From Handpumps to Health: The Evolution of Water and Sanitation Programmes in Bangladesh, India and Nigeria*. United Nations Children's Fund, New York, USA.

Boerschke, R. K. & Stewart, D. K. (eds) (2001). *Evaluation of Arsenic Mitigation Technologies for Use in Bangladesh*. Bangladesh University of Engineering and Technology and The United Nations University, Dhaka.

Chakraborti, D., Rahman, M. M., Das, B., Murrill, M., Dey, S., Mukherjee, S. C., Dhar, R. K., Biswas, B. K., Chowdhury, U. K., Roy, S., Sorif, S., Selim, M., Rahman, M. & Quamruzzaman, Q. (2010). Status of groundwater arsenic contamination in Bangladesh: A 14-year study report. *Water Research 44*(19), 5789–5802.

DPHE & JICA (2009). *Situation Analysis of Arsenic Mitigation 2009*. Local Government Division, Ministry of Local government, Rural Development and Cooeratives, Government of the People's Republic of Bangladesh, Dhaka.

Flanagan, S. V., Johnston, R. B. & Zheng, Y. (2012). Arsenic in tube well water in Bangladesh: health and economic impacts and implications for arsenic mitigation. *Bulletin of the World Health Organization 90*(11), 839–846.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy 31*(8–9), 1257–1274.

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory. *Research Policy 33*(6–7), 897–920.

GoB (2013). National Water Act. Retrieved from: http://www.mowr.gov.bd/images/pdf/WaterAct.pdf (accessed October 14 2014).

Hussam, A. (2009). Contending with a development disaster: Sono filters remove arsenic from well water in Bangladesh. *Innovations: Technology, Governance, Globalization 4*(3), 89–102.

Hussam, A. & Munir, A. (2007). A simple and effective arsenic filter based on composite iron matrix: development and deployment studies for groundwater of Bangladesh. *Journal of Environmental Science and Health – Part A Toxic/Hazardous Substances and Environmental Engineering 42*(12), 1869–1878.

Hussam, A., Ahmed, S. & Munir, A. K. M. (2008). Arsenic filters for ground water in Bangladesh: toward a sustainable solution. *The Bridge 38*(3), 14–23.

Johnston, R. B. & Sarker, M. H. (2007). Arsenic mitigation in Bangladesh: national screening data and case studies in three upazilas. *Journal of Environmental Science and Health – Part A Toxic/Hazardous Substances and Environmental Engineering 42*(12), 1889–1896.

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

Kabir, A. & Howard, G. (2007). Sustainability of arsenic mitigation in Bangladesh: results of a functionality survey. *International Journal of Environmental Health Research 17*, 207–218.

Kemp, R., Schot, J. & Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. *Technology Analysis & Strategic Management 10*(2), 175–198.

Khan, N. I. & Yang, H. (2014). Arsenic mitigation in Bangladesh: an analysis of institutional stakeholders' opinions. *Science of The Total Environment 488–489*, 493–504.

Kundu, D. K., Gupta, A., Mol, A. P. J. & Nasreen, M. (2016). Understanding social acceptability of arsenic safe technologies in rural Bangladesh: a user-oriented analysis. *Water Policy 18*(2), 318–334.

Markard, J., Raven, R. & Truffer, B. (2012). Sustainability transitions: an emerging field of research and its prospects. *Research Policy 41*, 955–967.

Milton, A. H., Hore, S. K., Hossain, M. Z. & Rahman, M. (2012). Bangladesh arsenic mitigation programs: lessons from the past. *Emerging Health Threats Journal 5*, 1–7.

NAISU (2003). An overview of Arsenic Issues and Mitigation Initiatives in Bangladesh. In: *NGOs Arsenic Information & Support Unit (NAISU) and NGO Forum for Drinking Water Supply & Sanitation*, pp. 1–125.

Pal, S. K., Adeloye, A. J., Babel, M. S. & Das Gupta, A. (2011). Evaluation of the effectiveness of water management policies in Bangladesh. *International Journal of Water Resources Development 27*(2), 401–417.

Paul, B. K. (2004). Arsenic contamination awareness among the rural residents in Bangladesh. *Social Science & Medicine 59*(8), 1741–1755.

Rammelt, C., Masud, Z., Boes, J. & Masud, F. (2014). Toxic injustice in the Bangladesh water sector: a social inequities perspective on arsenic contamination. *Water Policy 16*, 121–136.

Raven, R. P. J. M. (2006). Towards alternative trajectories? Reconfigurations in the Dutch electricity regime. *Research Policy 35*, 581–595.

Ravenscroft, P., Kabir, A., Hakim, S. A. I., Ibrahim, A. K. M., Ghosh, S. K., Rahman, M. S., Akter, F. & Sattar, M. A. (2014). Effectiveness of public rural waterpoints in Bangladesh with special reference to arsenic mitigation. *Journal of Water, Sanitation and Hygiene for Development 4*(4), 545–562.

Schilpzand, W. F., Raven, R. & van Est, Q. C. (2010). *Strategic Niche Management (SNM) beyond sustainability. An exploration of key findings of SNM through the lens of ICT and privacy*. Eindhoven Center for Innovation Studies Working Papers, 1–47.

Schot, J. & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. *Technology Analysis & Strategic Management 20*(5), 537–554.

Sekar, I. & Randhir, T. (2009). Arsenic contamination in water resources: mitigation and policy options. *Water Policy 11*(1), 67–78.

Shafiquzzaman, M., Azam, M., Mishima, I. & Nakajima, J. (2009). Technical and social evaluation of arsenic mitigation in rural Bangladesh. *Journal of Health, Population and Nutrition 27*(5), 674–683.

Smith, A. (2010). Translating sustainabilities between green niches and socio-technical regimes. *Technology Analysis & Strategic Management 19*(4), 427–450.

Smith, A. H., Lingas, E. O. & Rahman, M. (2000). Contamination of drinking-water by arsenic in Bangladesh: a public health emergency. *Bulletin of the World Health Organization 78*, 1093–1103.

Van Mierlo, B. (2012). Convergent and divergent learning in photovoltaic pilot projects and subsequent niche development. *Sustainability: Science, Practice & Policy 8*(2), 4–18.

Wieczorek, A. J., Raven, R. & Berkhout, F. (2015). Transnational linkages in sustainability experiments: a typology and the case of solar photovoltaic energy in India. *Environmental Innovation and Societal Transitions 17*, 149–165.

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