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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.

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 [2,6,17]. 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 [18,19,37]. 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 Refs. [16,19,23,26,36]. Furthermore, no single solution is feasible for all arsenic affected

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areas [10,11], 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 [33,34,40], 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 [8,29,40]. Several research and policy documents [12,30] 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 [1,22,39,40].

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 [8,29,40]. This paper conceptualizes this as "real world experiments" [13], 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 [4,32]. 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 Refs. [2,7,17,18,25,31]. 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.

2. Conceptualizing a socio-technical experiment

Transition theory puts much emphasis on radical innovation, considering it a driving force in stimulating societal change (see Refs. [9,35]. 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 [9,35]. These three levels include, first, the (*macro*) landscape level, which consists of rather inert contextual conditions against which specific socio-technical changes occur [9]. The second (*meso*) level consists of a socio-technical regime or a "stable configuration of culture, practices and institutions related to a specific domain (e.g., safe drinking water) [32]: 340). The final level is the *micro* level, which refers to protected spaces wherein radical innovations emerge and receive support [21]. 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 [9,14].

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 [32]; see in particular, [4]. 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 [4] 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 Fig. 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 [4].

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 [4]; 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 [4]: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" [4]: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

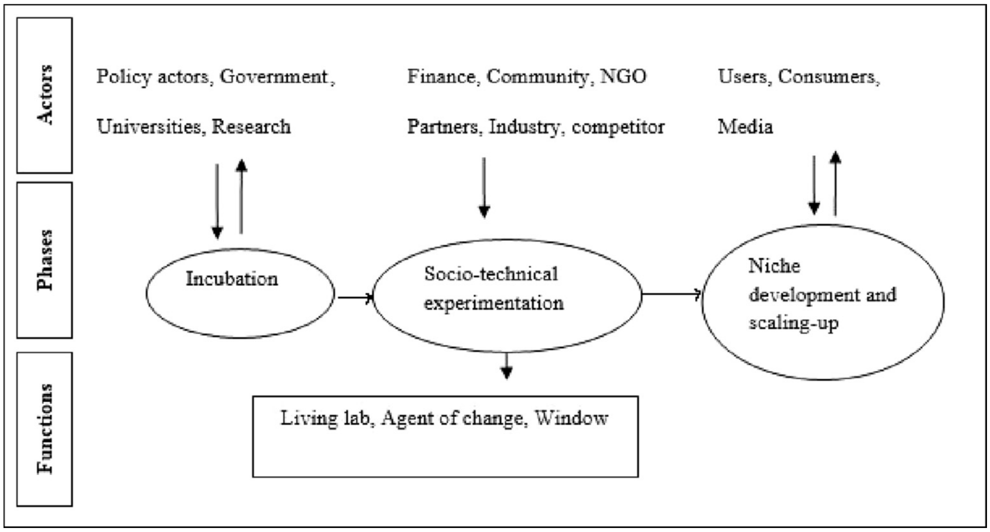

Fig. 1. Conceptualizing three phases and functions of socio-technical experiment (adapted from Ref. [4].

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.

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 [41]. 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 (subdistrict) of Comilla district, about 100 km 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 km 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 Ref. [24], 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 m 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.

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 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 Ref. [4]. To generate data on these, we developed detailed checklists to operationalize and assess the three functions in the course of our fieldwork (see Table 2). In doing so, we drew on 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 socio-technical 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 1).

Participants for consultation meetings were selected from community representatives, including community and religious

Table 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 In-depth interviews Focus group discussions	Three meetings, with a total of 55 villagers and community representatives Nine interviews with school authorities, scientists, DPHE engineers, and personnel at hardware shops 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 Consultation meetings In-depth interviews	Respondent set consisted of 134 villagers Three meetings, with a total of 43 community representatives 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

Table 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.

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 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.

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).

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 Ref. [40]. This earlier research in Bangladesh had attracted the interest of governmental (DPHE) and non-governmental (UNICEF) organizations, and these local stakeholders encouraged the Dutch team of researchers to continue with

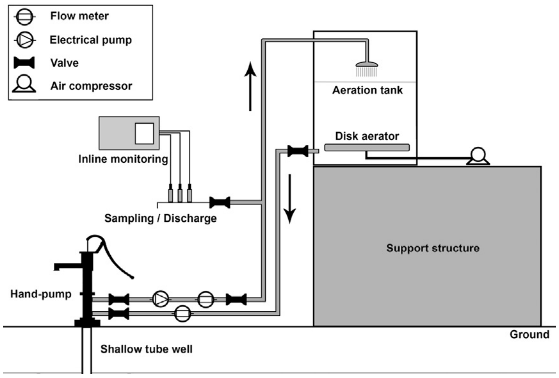

Fig. 2. Prototype of sub-surface arsenic removal technology [8,29].

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, non 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.

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[1] of SAR technology (see Fig. 2) with the aim to make it attractive to potential users and investors by 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 [29].

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 m from each other, the research team drilled two new shallow tube wells (20.5 and 22.5 m deep) by using the "sludger" method [3]. 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 L 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 Ref. [29].

As noted in section 1, the operation of SAR involves three consecutive steps [40]. This first experiment A was designed to determine the impact of alternative operations on SAR performance [29]. 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 L of arsenic safe water after the injection of 1000 L 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.

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 Fig. 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 Fig. 3 below).

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

[1] 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/).

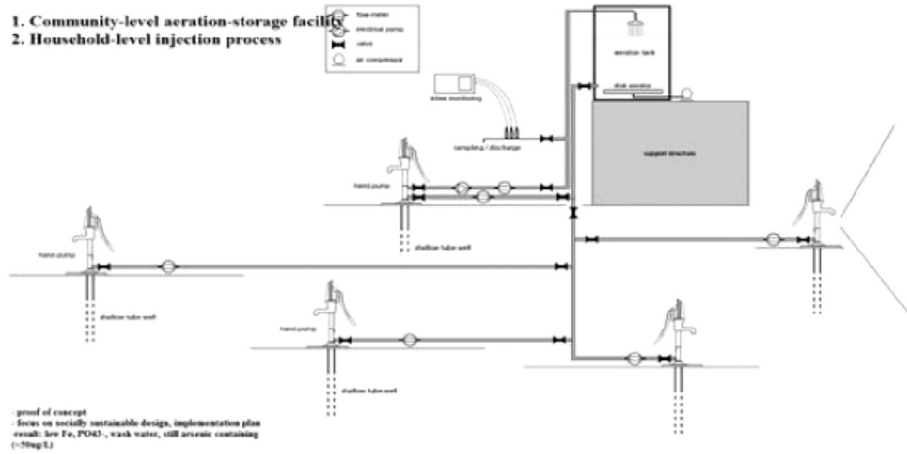

Fig. 3. Experimental design of community level iron removal at subsurface and hand-pump arsenic removal for household scale of use [8].

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 100 μg/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 L capacity for aeration and 2000 L 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 Fig. 4).

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 L 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 [29]. In total, the cost for 1000 L 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.

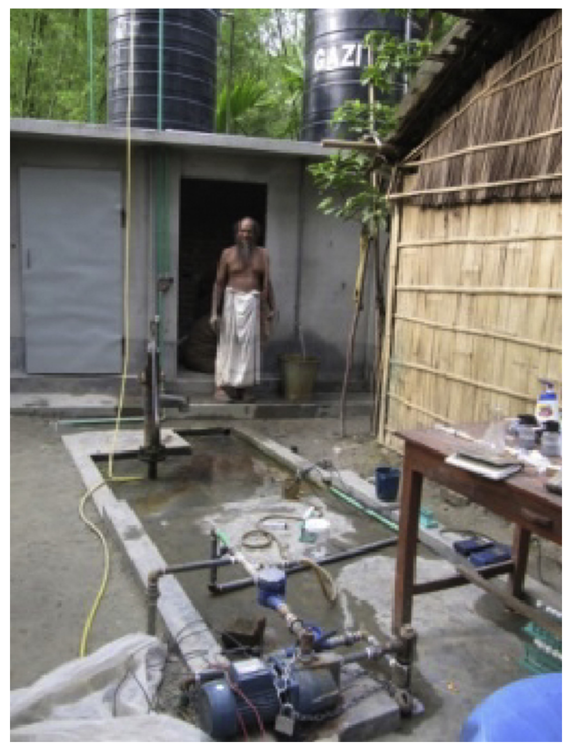

Fig. 4. Caretaker in front of SAR unit experimentally deployed in Bangala village.

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 L of treated water was required to meet the daily demand of users, whereas the maximum production capacity of SAR was 2000 L 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. 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*.

5.1. 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.*

5.2. 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, dys functionalities 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 m. The average household size was 5.5 members and the amount of drinking water needed per household was 17.9 L 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*.

5.3. 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 emphasizing … 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' long-standing 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*.

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 3).

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 [28]. 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

Table 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 belief systems, practices and institutions reflect a preference for a technology linked to the household-level shallow hand pump tube well. Various aspects of culture, beliefs, practices and institutions relevant to assessing the prospects for future successful deployment were identified via SAR experiments, hence it served as a living lab.
Window (experiments are utilized as communication and conversation tools to build support and legitimacy by raising actors' interest and enrolling new actors)	Working prototypes (and visuals) of SAR were used as communication and conversation tools; the experimental SAR community spot was used as a physical space for social gatherings; initially, the second experiment (B) raised users' interest and enrolled new users. 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 users that would be necessary for niche development and scaling up of the SAR innovation.

Source: Authors analysis, based on fieldwork 2011–2014.

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., [15,17,27,36]. 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, the 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 [19,20,26,38]. 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 behavioural 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.

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 Fig. 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 [9]. In this regard, a demarcation between pre-niche and niche formation in testing and uptake of radical innovations can be useful (see Fig. 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

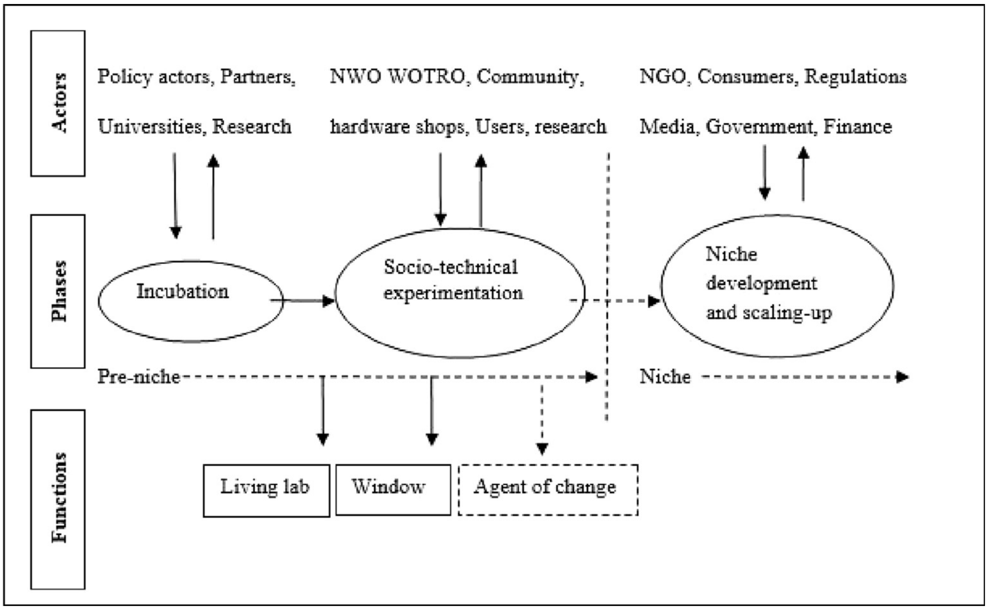

Fig. 5. Distinction between pre-niche and niche: fulfilling pre-niche conditions as a prerequisite to niche development.

whether Bangladesh will set the WHO guideline value of 10 μg/L as an acceptable limit of arsenic level in drinking water.[2] In that case, SAR would need to achieve this new target. Results of alternative SAR operations presented in Ref. [29] showed that arsenic levels in the extracted water were close to the WHO guideline value for considerable volumes. It was also recommended by Ref. [29]; 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.

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.

[2] 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.

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Annex 1. Cross-section of sample questions used for data generation about the three functions of sociotechnical experiments (in-depth interviews, focus groups, surveys, and consultation meetings)

1. Could you please tell us about your socio-economic background?

[Name, age, years of education, occupation, self-perceived socio-economic status of household (always surplus, sometimes surplus, break-even, sometimes deficit and always deficit), ownership of shallow hand pump tube-well etc.]

2. Could you please tell us about your drinkingwater 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.]

3. 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?

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