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

Debasish Kumar Kundu\textsuperscript{a,b}\textsuperscript{*}, Bas J.M. van Vliet\textsuperscript{a} and Aarti Gupta\textsuperscript{a}

\textsuperscript{a}Environmental Policy Group, Wageningen University, Hollandseweg 1, Wageningen 6706 KN, The Netherlands
\textsuperscript{b}Department of Sociology, University of Dhaka, Dhaka 1000, Bangladesh

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

Keywords: arsenic mitigation, Bangladesh, deep tube well technology, drinking water, Multi-Level Perspective on transitions

1. Introduction

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

\textsuperscript{*}Corresponding author. Email: debasish.k@du.ac.bd; kundudev@yahoo.com

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

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

We proceed as follows: the next section presents our conceptual approach based on the Multi-Level Perspective (henceforth MLP). Section 3 presents our research methods, study area, and research approach. In Section 4, we present our findings and Section 5 contains a discussion and conclusions.

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

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

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

With regard to change mechanisms, there is no a priori expectation about which one takes precedence over another. Furthermore, assessment of change mechanisms can only occur in specific contexts. In assessing the conditions under which a given change mechanism comes to the fore in our case, we proceed as follows: we first analyse the nature and extent of the changes, if any, to the seven dimensions of the safe drinking water socio-technical regime, resulting from introduction of the deep tube well. We then assess the overarching change mechanism this represents for the safe drinking water regime in rural Bangladesh. In other words, by studying the magnitude of change taking place in the seven dimensions of a regime, we can assess how and why (i.e. through what change mechanisms) the deep tube well has become dominant in the context of arsenic mitigation (see Figure 1). Our overarching aim is to shed light on the pathways of stabilisation and/or change.

![Figure 1: Multi-level pathways of change in a socio-technical regime. Source: Rip and Kemp (1998); Geels and Kemp (2007).](image-url)
(reproductive, transformative, or transition) that can help explain the consolidation and dominance of deep well technology in the safe drinking water regime in the context of arsenic mitigation in rural Bangladesh.

3. Methods

To understand the dominance of deep tube well technology in the safe drinking water socio-technical regime in the context of arsenic mitigation, a case study methodology was followed, with use of qualitative and quantitative data collection methods. Qualitative data about the safe drinking water socio-technical regime were collected from regime actors using in-depth interviews, focus-group sessions, and workshop (see Table 1). The purpose of in-depth interviews and focus-group sessions was to gather data on the seven dimensions of the socio-technical regime. The purpose of the workshop was to generate information on the allocation, installation, infrastructure, and availability of deep tube well technology in the context of, but also beyond, arsenic mitigation in rural Bangladesh. A semi-structured questionnaire was also distributed and was designed to gather quantitative data from deep tube well users on technological attributes, user practices, and techno-scientific knowledge.

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

We conducted 47 in-depth interviews with regime actors related to innovation and dissemination of deep tube well (see Table 1). In addition, four focus-group sessions, including two with only male or only female users, were organised. Furthermore, one workshop

Table 1: Techniques of data collection and respondents.

| Techniques                          | Respondents (number)                      |
|------------------------------------|------------------------------------------|
| In-depth interviews                | 3 Policy-makers from policy support unit  |
|                                    | 3 Donors: 1 each from UNICEF, JICA, and WHO |
|                                    | 10 Implementing agencies: 6 with the DPHE, 2 with BRAC, and 1 with NGO Forum for Public Health |
|                                    | 6 Engineers from the DPHE                |
|                                    | 9 Community representatives             |
|                                    | 6 Scientists and experts: 1 each from BCSIR, BUET, DU, and 3 independent experts |
|                                    | 4 Hardware shops                        |
|                                    | 3 Foundry industries                    |
|                                    | 3 Masons                                |
| Focus-group sessions               | 2 Female and 2 male users               |
| Survey questionnaire               | 99 Households                           |
| Workshop on prospects and challenges of disseminating arsenic mitigation technologies in Uttar Suchipara Union | 15 Participants including Upazila chair, Union Parishad chair and members, community leaders, DPHE engineer, BRAC executive, and users |
was organised, where 15 regime actors participated, including DPHE, Upazila Parishad, Union Parishad, government officials, NGOs, community representatives, and users.

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

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

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

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

An estimated 165,000 deep tube wells were installed between 2000 and 2005 throughout the country, mostly by the Department of Public Health Engineering (Ahmed et al., 2006; Escamilla et al., 2011). Within a few years, the number had increased to 195,603 (DPHE Planning circle, 2007) (DPHE and JICA, 2009). Figure 2 presents a consistent trend of recent national-level dissemination of 70,648 deep tube wells from 2006 to 2011. Besides, several NGOs installed deep tube wells through various arsenic mitigation projects. According to a compilation by Ravenscroft et al. (2009), the deep tube well technology has become dominant (84.4%) among the arsenic mitigation technologies followed by safe shallow hand pump tube wells (5.1%) and improved dug wells (4.9%), rainwater harvesting (3.2%), and pond sand filters (1.4%) (see Figure 3).

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

Originally, a deep tube well was a manually operated drilled well like the shallow hand pump tube well, except that it pumps water from a depth of 150 metres (see Figure 4). The UNICEF Number 6 hand pump (with suction mode) was the widely used hand pump model for shallow hand pump tube wells. For many years, these deep tube wells used to attach an Indian Mark II hand pump to a Number 6 pump-head, which did not perform well. As part of research and development, Tara, Tara II, and Tara Dev (force mode hand pump) were developed, of which Tara (direct vertical action) was not appreciated by the women users because of the difficulty entailed in pressing down the handle. Along with Number 6 pump-head, Tara Dev (liver action) has been installed in the arsenic-contaminated areas of Bangladesh. All the materials necessary for deep tube well and shallow hand pump tube wells were the same, although few modifications have been made over time. These included substitution of polyvinyl chloride (PVC) for galvanised iron pipe for well casing and PVC buckets instead of old leather buckets. Otherwise, all other materials – seat valves, nuts, bolts, and cement for contraction of platforms – remained the same.

Regarding installation issues, the ‘sludger method or hand percussion drilling’ method that was useful for installing shallow hand pump tube wells needed to be replaced by a ‘direct circulation rotary drilling locally known as donkey drilling’ method to drill a deep tube well, which is costlier. The workshop¹ with practitioners highlighted the technical advantages of deep tube well

![Figure 2](image-url)  
**Figure 2**: Year-wise number and trend of dissemination of deep tube well technology in Bangladesh by the government.  
Source: Management Information Unit, DPHE, Dhaka, April 2013.

![Figure 3](image-url)  
**Figure 3**: Deep tube well alone provides 84.4% of arsenic mitigation (Ravenscroft et al., 2009; DPHE and JICA, 2009).
technology: (i) it could provide safe drinking water without any further treatment and (ii) no electricity input was required. Female participants in the focus-group session revealed that deep tube well had technical supremacy over other arsenic mitigation technologies, referring to a community-level arsenic removal plant that required chemicals and electricity. All the respondents in the workshop recognised that the deep tube well technology was not entirely new to them. Hence, we found that the deep tube well technology is perceived to be an incremental (modified or updated) version of existing shallow hand pump tube well, with competitive advantages over other arsenic mitigation technologies.

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

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

One deep tube well is able to serve at least 10 households; hence it is seen as a community-level technology. Our survey (see Table 2) shows that 73.70% of the users knew how to use the deep tube well, whereas 67.7% users were comfortable with its design. The technology was seen as simple to operate by 65.7% users and 56.6% appreciated its easy maintenance. Although only few (2.8%) users received training in use of this technology, and only 21.2% of those surveyed were concerned about arsenic contamination, a major proportion (92.8%) of users believed that the water they drank from the deep tube well was arsenic safe. Similarly, 75.8% of users found that the deep tube well technology was able to meet drinking water demand of households. In addition, 96% of users started using deep tube well willingly. It was, however, graded as labour intensive by a majority of users (75.8%). During summer,
when water levels are low, the task of drawing water through pressing the handle was seen as laborious for female users, with the amount of pumped water also falling. An NGO official\(^4\) mentioned that these problems are not new; however, users had similar experiences with using shallow hand pump tube wells as well.

Using a community-level technology, such as the deep tube well, required a shift from a ‘private’ individual source of safe drinking water to a shared source, as mentioned by the users.\(^5\) In addition, this shift was often time and labour consuming, putting additional burden on women, who were traditionally responsible for managing drinking water. Users also agreed, however, that the installation of more deep tube wells within a neighbourhood had started to reduce this burden in recent years. An engineer\(^6\) mentioned that this shift from household to community-level use was challenging for female users, but it was not entirely new in terms of existing safe drinking water practices. For example, one-third (29.3%) of the deep tube well users had to collect drinking water from adjacent neighbourhoods previously, given that they had no shallow hand pump tube well in their own household.

We find that evolving user practices with deep tube well technology are largely aligned with existing practices, in place for shallow hand pump tube wells. One additional aspect relates to affordability and existing practice regarding costs of securing safe drinking water. Since the installation costs of deep tube wells are high (US$900), 46.5% users found it affordable only when it was highly subsidised by the arsenic mitigation projects. Therefore, market actors had no direct connection with users unless the implementing agencies (government or NGOs) mediated between them. However, we identified 15 incidences where rich families installed deep tube wells in their households by spending private money.

With regard to this situation, the owner of a hardware shop\(^7\) found a similarity with the early days of disseminating of shallow hand pump tube well, when the government and NGOs procured the technologies to supply to the users in a similar way. An expert\(^8\) mentioned that the market should directly be involved with the dissemination of deep tube well technology because it

![Table 2: Selected variables relevant to user practices by the deep tube well users (N = 99).](image)
costs much less per capita than other arsenic mitigation technologies. As such, the unit cost of deep tube well technology (0.151US$/m³) is much lower than other arsenic mitigation technologies, for instance, 0.407US$/m³ for piped water supply and 0.353US$/m³ for removal or treatment technologies. Our findings reveal that despite its high public demand as an arsenic mitigation technology, high capital cost involved with the installation serves as a hurdle in establishing a direct link between users and the market. In terms of arsenic mitigation, however, project-based dissemination played a crucial role in the growing dominance of deep tube well technology as the mitigation option of choice.

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

4.3. Symbolic meaning attached to the deep tube well

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

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

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

Infrastructure refers to the organisation of associated activities related to the dissemination of deep tube well technology within arsenic mitigation and rural water supply projects. The DPHE organised the bulk of the deployment of the deep tube well technology, as the government was primarily responsible for providing safe drinking water to rural populations. The allocation of the deep tube well was done in a top-down way, with decisions made by the DPHE head office. The union-wise allocation of deep tube well was executed by the DPHE Upazila (administrative subdistrict) office, following the recommendations of the Upazila water, sanitation, and hygiene (WATSAN) committee. Similarly, village-wise allocation was administered by the Union’s WATSAN committee, under which Union Parishad (UP, elected body of the lowest administrative unit of local government) mobilised a 10-member water user group and obliged it to select a suitable spot for installing a deep tube well for community-level use. The workshop revealed that it was not possible by the DPHE to allocate deep tube wells to poorer families, without also involving the influential wealthier families. In this regard, UP developed an informal mechanism for group formation by including a rich family in the group as a host household, who would take on the responsibility to finance part of the installation, operation, and maintenance costs of the technology. In doing so, the UP sought to mitigate power conflicts among the local actors, and also ensured the long-term sustainable use of the deep tube well technology.

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

Our findings reveal that this organisational infrastructure, consisting of water user groups, host households (caretakers), Upazila and Union-level WATSAN committees, and the DPHE favoured the dissemination of deep tube well in arsenic-affected areas. All these actors had long been involved in disseminating shallow hand pump tube wells, in the pre-arsenic contamination era. In the 1970s, Union board members – an administrative unit comprising several villages – were involved in the dissemination of shallow hand pump tube wells by the DPHE (Black, 1990). Similarly, during 1973–1974, the Dhamrai pilot project involved a UP to manage cost sharing and supervise installation of shallow tube wells, although with somewhat limited success (Black, 1990). As such, a new system of maintenance was introduced in 1976, in which a caretaker (selected from 10 user households) received training under an extension of the DPHE programme to NGOs (Black, 1990). Furthermore, the provision of cost sharing was first introduced in 1976, when users contributed 50–75% of the installation cost.

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

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

4.5. Industry involvement and structures

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

Our data also show that approximately 40 foundry companies were established to manufacture 30 designs (based on size and weight) of hand pumps suitable for both shallow and deeper depths. About 90% of the necessary cast iron is available in local markets, with the rest imported from India and China. Additionally, a shift from galvanised iron pipes to PVC plastic pipes in 1997 contributed to cost reduction of tube wells, according to a hardware shop owner. Furthermore, widely established hardware shops and retailers throughout the country provided a number of services, including the supply of materials, transportation, installation, and repair. Therefore, the existing industry structures enabled both users and implementing agencies to access the technology, with spare parts available in the local market. This was confirmed by 54.5% of our survey respondents (Table 2).

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

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

Another key dimension of the existing regime that we examine here is the policy context shaping dissemination of deep tube well technology. Several policies and government acts provided the institutional and regulatory context within which innovation and dissemination of deep tube well technology in the context of arsenic mitigation became successful. For example, the National Policy for Safe Water Supply and Sanitation (GoB, 1998) and the National Arsenic Mitigation Policy (NAMP) (GoB, 2004a) mandated the DPHE to play central roles in planning, implementing, and maintaining the provision of safe drinking water options in rural contexts. In addition, the Local Government Act (GoB, 2009b) assigned the UP a direct role in supply, management, and conservation of water resources. The National Water Policy (GoB, 1999) provided guidelines for the formation of community-based organisations (for instance, water user groups) to maintain community water points. Furthermore, the National Industrial Policy (GoB, 2010) encouraged the establishment of tube well manufacturing industries with the provision of tax holidays. The involvement of DPHE, UP, manufacturing industries, and user groups were shaped by these policies.

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

As another important element, a provision of cost sharing was required by all the relevant policies, such as the National Policy for Safe Drinking Water Supply and Sanitation (GoB, 1998), NAMP (GoB, 2004a), and IPAM (GoB, 2004b). Although IPAM restricted cost recovery mechanisms in the highly arsenic-contaminated areas, it was found that a water user group consisting of

![Figure 5: Year-wise number and trend of dissemination of deep tube well by the DPHE at Uttar Suchipara Union. Source: DPHE office, Shahrasti, Chandpur, April 2013.](image-url)
10 households contributed US$56 (about 5% of installation cost) for getting a deep tube well. Male focus-group respondents confirmed their support of this by noting that ‘provision of cost sharing for installation and maintenance (100%) ensures our combined ownership’. Similarly, a DPHE engineer and policy-maker confirmed that the government would continue disseminating the deep tube well technology to ensure comprehensive access to safe drinking water in arsenic-contaminated areas, wherever this option was technically feasible. Figure 5 shows annual installations of deep tube wells in Uttar Suchipara Union, indicating a growth trend similar to national growth trends (Figure 2). Additionally, the Bangladesh Rural Advancement Committee (BRAC), a national NGO, also disseminated 31 deep tube wells for community-level use in the same union.

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

4.7. Supportive techno-scientific knowledge

Scientific evidence regarding the safety of available drinking water sources in the context of arsenic contamination has also been an important dimension of the socio-technical safe drinking water regime, and one that has again supported the widespread dissemination of deep tube well technology. A tube well deeper than 150 metres is widely acknowledged to be safe from arsenic contamination, as authoritatively claimed by a scientific report (BGS and DPHE, 2001). This report was considered a milestone in discussions around arsenic mitigation options (DPHE and JICA 2009). As an engineer from the DPHE pointed out, available scientific knowledge enabled users to shift from the shallow tube well to the trustworthy deep tube well technology. The perceived trustworthiness of this option was also reflected in the user views: for instance, a majority of users (92.9%) believed that a deep tube well provides arsenic safe water (Table 2).

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

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

5. Discussion and conclusion

This paper started with the assertion that deep tube well technology has become the dominant arsenic mitigation option in rural Bangladesh. Earlier explanations of such dominance have focused on the technical attributes and social acceptability of this technology. In addition to these existing insights, we have sought in this paper to explain why and how the deep tube well has become the dominant arsenic mitigation option. We have done so by studying the
magnitude of change occurring in seven dimensions of the existing safe drinking water socio-technical regime that have resulted from increasing use of the deep tube well, and the change mechanism underpinning these, in the specific context of arsenic mitigation in Bangladesh (Table 3).

| Regime dimensions | Shallow tube well dominant | Deep tube well dominant | Transformation as a change mechanism |
|-------------------|---------------------------|-------------------------|--------------------------------------|
| Technological attributes | Ease of access, maintenance, and use of shallow tube well. Few deep tube wells in coastal areas and areas with low water table | Deep tube well as an incremental innovation with competitive advantages over other arsenic mitigation technologies (given technological attributes similar to shallow tube well) | Levels involved: There is interaction between regime and landscape. Landscape pressure (arsenic crisis) destabilises existing safe drinking water regime. With the introduction of deep tube well as an arsenic mitigation technology, adaptation and reorientation in the seven dimensions helps to transform the existing safe drinking water regime and re-stabilize it. |
| User practice and application domain (market) | User practices support household level of use. Users directly linked with market | Adaptation to community level of use. No direct connection between market and users; implementing agencies mediate through arsenic mitigation projects | Role of actors: Due to pressures from international agencies, incumbent regime actors, including the government and NGOs, respond through reorienting policies and infrastructures for provision of safe drinking water through an incremental innovation such as deep tube well. |
| Symbolic meaning | Shallow tube well as a miracle technology, symbol of status and progress | Deep tube well has a similar symbolic meaning | |
| Infrastructure | Managed privately, government and NGOs involved | Re-orientation through involvement of the DPHE, UP, and users; adaptation from ‘private’ to ‘community’ operation | |
| Industry structure | Already developed, including foundry industries, hardware shops, and masons | No new industry structure needed, adaptation through provision for cost sharing | |
| Policies | Preference for installation of shallow hand pump tube wells, no restriction on deep tube well | Although surface water technologies preferred, in practice deep tube well promoted | |
| Techno-scientific knowledge | Arsenic contamination of shallow tube well scientifically established; 29% shallow hand pump tube wells found unsafe | Deep tube well a safer option for the arsenic-contaminated areas, installation and use did not require new knowledge. It has emerged as a problem-solving technology in the context of arsenic mitigation | |
We found that technologically, the deep tube well is an incremental version of the shallow hand pump tube well that was deployed long before the arsenic crisis emerged, but only in areas with salinity and low water tables. It has competitive advantages (for instance, a long life span, easy operation and maintenance, and no requirement for water treatment) over other arsenic mitigation technologies. Although evolving user practices with deep tube well were aligned with those of shallow hand pump tube wells, adaptation from ‘private’ to ‘community’ operation was challenging. This challenge has gradually been overcome with a community management approach introduced by intermediary implementing agencies (Ahmad et al., 2006). Despite the huge public demand for the deep tube well in arsenic-contaminated areas, high capital costs involved with its installation have prevented the establishment of a direct link between users and the application domain (market). In this connection, arsenic mitigation and safe drinking water projects implemented by the government and NGOs make this technology available to users through cost sharing. Like shallow hand pump tube well, the deep tube well secures its position as a ‘miracle technology’ that denotes a long-term assurance of safe drinking water. It is also synonymous with social status and progress in rural society.

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

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

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

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

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

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

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

In contrast to the literature on arsenic mitigation that presents the deep well tube as preferred technology because of its individual technical attributes or social acceptability, this paper has shown that social or technical performance alone cannot explain technological dominance. Various inter-related dimensions of the existing safe drinking water regime need to be supportive, or be adaptable, to secure the dominance of this specific technology. We conclude as well that the application of incremental innovation in a developing country context is useful, even when an existing regime is less stable. Our analysis contrasts with the existing assumption within the MLP that incremental innovation performs well only in a stable regime (see e.g. Geels and Kemp, 2007). As such, our analysis highlights the context-specific conditions under which the MLP on transition has explanatory power in developing country contexts.
In addition, our analysis contributes to the existing literature on arsenic mitigation in Bangladesh by offering an integrated analysis of regime dynamics and change mechanisms, with an emphasis on a particular technological innovation. Specifically, identifying transformation as the change mechanism through which the deep tube well has become dominant is a concrete contribution of our paper. This study also yields insights for arsenic mitigation policy implementation, in particular, by reaffirming that incremental innovations remain critically important to mitigating the arsenic crisis in Bangladesh.

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**Notes**

1. Author organised a workshop on January 7, 2012 at Shahrasti Upazila Chairman’s office.
2. Author organised a focus-group session with female participants on December 25, 2012 at Uttar Suchipara village.
3. One Sidko arsenic plant was installed at Uttar Suchipara Union in 2003 by two voluntary organisations.
4. Author’s interview with the BRAC manager on January 12, 2012 at Shahrasti BRAC office.
5. Author organised a focus-group session with female participants on December 25, 2012 at Uttar Suchipara.
6. Author’s interview with a DPHE engineer on December 29, 2012 at Shahrasti DPHE office.
7. Author’s interview with the owner of a hardware shop on January 19, 2013 at Shahrasti.
8. Interview with an expert of UNICEF on March 9, 2012 at Dhaka UNICEF office.
9. [http://siteresources.worldbank.org/EXTWAT/Resources/4602122-1213366294492/5106220-1213389414833/11.2Technology_for_Arsenic_Mitigation.pdf](http://siteresources.worldbank.org/EXTWAT/Resources/)  
10. Author’s interview with a DPHE engineer for arsenic mitigation on December 29, 2012 at Dhaka DPHE office.
11. Author organised a workshop on January 7, 2012 at Shahrasti Upazila Chairman’s office.
12. Author organised a focus-group session with male participants on November 19, 2012 at Uttar Suchipara.
13. Author’s interview with a media expert on October 14, 2013 at Dhaka.
14. Upazila Water, Sanitation and hygiene (WATSAN) committee, consists of 23 members where Upazila chair and sub-assistant engineer of DPHE performs as president and secretary, respectively. UP chairs, concerned government officers, and representatives from NGOs are included as members. The Union WATSAN committee consists of 17 members and is headed by the UP Chair.
15. Author organised a workshop on January 7, 2012 at Shahrasti Upazila Chairman’s office.
16. Author’s interview with the UP chair on November 11, 2012 at Uttar Suchipara.
17. Author’s interview with the human resource manager of Rangpur Foundry Limited on December 13, 2013 at Dhaka.
18. Author’s interview with the owner of a hardware shop on December 23, 2013 at Dhaka.
19. Author’s interview with the policy-maker of Policy Support Unit on July 25, 2013 at Dhaka.
20. Interview with a scientist on May 15, 2014 at Dhaka.
21. Author organised a focus-group session with male participants on November 19, 2012 at Uttar Suchipara.
22. Author’s interview with a DPHE engineer for arsenic mitigation on December 17, 2012 at Dhaka DPHE office.
23. Author’s interview with policy maker of Policy Support Unit on July 25, 2013 at Dhaka.
24. Author’s interview with an expert on July 22, 2012 at Dhaka University.
25. Author’s interview with a DPHE engineer for groundwater on August 18, 2013 at Dhaka DPHE office.
26. Author’s interview with a retailer shop on November 23, 2014 at Dhaka.
27. DPHE (2013), Official Document, collected from: C:\Documents and Settings\USER\Desktop\Rupkolpo.11-12(Water Supply-1).doc, accessed on: January 12, 2014.
28. Target 7c states ‘halving by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation’ retrieved from: https://sustainabledevelopment.un.org/content/documents/981bangladesh.pdf

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Appendix. Study area.