Developing sustainable models of arsenic-mitigation technologies in the Middle-Ganga Plain in India

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This study seeks to understand factors that guide the decision-making process to adopt and implement the available arsenic-mitigation technologies in rural areas in the middle-Ganga Plain in India. A total of 340 households comprising 2500 people were surveyed. Socio-economic and demographic factors, water and sanitation status, time spent and distance travelled to collect water, arsenic awareness, willingness to pay (WTP) for arsenic-free water, people's trust in others and in institutions, social capital in communities, and preferences for sustainable arsenic-mitigation options were investigated. Arsenic treatment units (filters) and piped water supply systems were the most preferred sustainable arsenic-mitigation options in the surveyed villages. Less preferred arsenic-mitigation options include deep tube wells, dug wells, and rainwater harvesting systems. Binary logistic regression models for each arsenic-mitigation option were produced. Arsenic awareness, WTP, trust in agencies, trust in institutions and social capital were found to be the most significant factors for decision-making for preferring one arsenic-mitigation technology over the others. We recommend a mixed model of two arsenic-mitigation options for the studied individuals, which could be a sustainable arsenic-mitigation option for them, considering their socio-economic and demographic conditions. Existing institutions should be strengthened, agencies empowered, and communities enlightened about arsenic problems.

Keywords: Arsenic-mitigation, arsenic treatment unit, deep tube well, dug wells, piped water supply, rainwater harvesting system.

WIDESPREAD geogenic groundwater arsenic contamination is one of the biggest challenges for policy makers, researchers, and communities to ensure that arsenic-free potable water is available for more than 12 million people in the Middle-Ganga Plain (MGP) in India[1–4]. The potentially exposed population in MGP is far beyond the potentially exposed populations in Thailand, Chile, Bolivia, Mexico, Hungary, Spain, Greece, Ghana, and other arsenic-contaminated areas across the globe[5,6]. In MGP, about 87% of the tested groundwater sources were found to be contaminated with arsenite, the most toxic form of arsenic[7]. Arsenic concentrations beyond standards set by the World Health Organization (WHO) for drinking water and the standard set by the United Nations Food and Agriculture Organization (FAO) for irrigation water, as well as elevated levels of arsenic in soils and food materials have also been reported in the region[4,8,9]. Arsenic concentrations in groundwater in the MGP (>1000 μg/l) exceed several folds, the arsenic levels reported in groundwater in many other countries[5,10]. Moreover, several arsenicosis symptoms and cancer risks due to the consumption of arsenic-contaminated groundwater and food in some of the arsenic-affected areas in the MGP have been documented[1,11,12].

Arsenic-mitigation and associated technological and socio-economic challenges

Several arsenic-mitigation interventions have been implemented in arsenic-contaminated areas worldwide, but have encountered technical challenges. These include but are not limited to low arsenic removal efficiency and interference generated by iron, high sludge volume, high costs for capital, operation, maintenance and failure to remove other contaminants such as phosphate and iron present in groundwater[13–15]. Additionally, beneficiaries have to pay for arsenic removal filters, but most of the arsenic-mitigation technologies are not designed according to the geographical needs of the intervention areas. For example, rainwater harvesting units were installed in low precipitation areas[15].

The socio-economic factors of communities in arsenic-contaminated areas have been found to be major players in the failure of arsenic-mitigation interventions worldwide. These factors include cultural background, low willingness to pay (WTP) for arsenic-mitigation technologies, lack of awareness about arsenic, lack of ownership of the arsenic-mitigation technologies, and distance and travel time required to collect arsenic-free drinking water by communities[15]. Additionally, non-cooperation of owners

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of safe tube wells, bad taste of water after treatment, denial of the presence of arsenic contamination, misconception that boiling water removes arsenic and lack of safe drinking water sources near houses have all contributed to the failure of arsenic-mitigation programmes[16]. Low implementation of arsenic filters is also due to lack of pictorial instructions in the operating manuals in low literacy areas, lack of transparency between the service providers and the users regarding the actual cost of arsenic filters, social knowledge, and installation of arsenic removal plants that are inaccessible to communities[13,15,17].

Failure of arsenic-mitigation programmes contributes to several socio-economic adversities. The most important socio-economic predicaments associated with arsenic pollution include 'social uncertainty, social injustice, social isolation, and problematic family issues', among others[18]. However, the poor suffer the most. They suffer from dietary deficiencies and lack of alternative sources of safe drinking water. Arsenic pollution further contributes to social stigmatization, social discrimination, and social conflicts among the communities. Therefore, it destroys social harmony and network relationships[18]. For example, arsenic-affected students are barred from schools and arsenic-affected people are generally avoided by friends and colleagues and hated by others[18]. Under extreme conditions, women are abandoned, divorced or separated, or sent back to their parents by their husbands[1,16,18]. Women also suffer from overly expensive dowries, physical torture, and polygamy[16,18]. Therefore, women affected by arsenicosis were found to be more frequent social victims than men [18]. Wives may also separate from an arsenic-affected spouse due to fear of becoming sick. Arsenic-affected families are isolated by their communities and refused any marital relationships within them[18].

Current status of arsenic-mitigation in the project area

The current study was conducted in Bihar, an eastern state of India, and located in MGP. The Public Health Engineering Department (PHED) of the government of Bihar, the nodal body responsible for providing safe drinking water, initiated several mitigation schemes including renovation of open dug wells, construction of sanitary wells, deep tube wells, rainwater harvesting systems, addition of India mark III hand pumps to wells, installation of arsenic-removal plants, construction of community-based systems to draw arsenic-free water from deep aquifers, and extracting water from River Ganga[19,20]. Until now, there have been no reported studies to evaluate the functionality or sustainability of arsenic-mitigation programmes in the state. Therefore, it is difficult to assess which of the arsenic-mitigation technologies are the most successful and sustainable in Bihar.

Several socio-economic and demographic factors, listed in the previous section, play a vital role in understanding the reasons behind the failure of arsenic-mitigation programmes globally. It is necessary, but not enough, to take inventory of the successful arsenic-mitigation technologies and determine what percentage of population uses these technologies. This study seeks to understand factors that guide the decision-making process to adopt and implement available arsenic-mitigation technologies. To our knowledge this is the first study of arsenic-exposed communities in MGP that evaluates the socio-economic, demographic and other social factors and preferences for sustainable arsenic-mitigation options. The central goal is to develop a sustainable socio-economic arsenic-mitigation model, one that is easily interpretable for policy makers dealing with arsenic-mitigation. We selected three villages (Suarmarwa, Rampur Diara, and Bhawani Tola) (Figure 1) in Maner block (a highly arsenic-contaminated community block) of Patna district of Bihar, India[4,6,8,9,12]. A detailed arsenic survey report in these villages is presented elsewhere[4,6].

Materials and methods

Survey administration is explained in detail by Singh[6]. In brief, a stratified sampling technique was applied to survey 340 households (2500 individuals in total) in three villages: Suarmarwa, Rampur Diara, and Bhawani Tola of Maner block of Patna district in Bihar, India.

Statistical analysis and modelling

All statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) version 21 for Windows[21]. To evaluate the independence of each variable across the three surveyed villages, a χ^2 test was performed. In this study, the response variables were

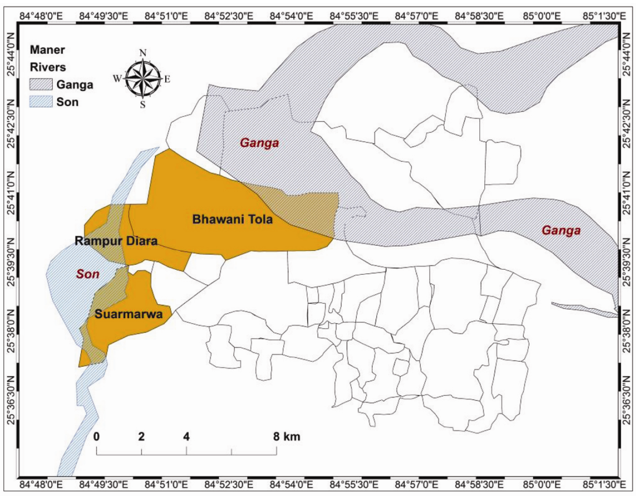

Figure 1. Study area showing three villages in Maner block of Patna district, Bihar, India.

dichotomous in nature and the predictors were continuous and categorical. Therefore, a logistic regression modelling technique was applied to fit the model to the data.

Logistic regression models the probability of presence and absence of the response, given the observed values of the predictors[22–24]. Moreover, it explains the relative contribution of each predictor to the response, controlling for the influences of the rest of the predictors in the model[22,23]. Additionally, logistic regression establishes a functional relationship between the binary coded preferences for arsenic-mitigation technology and the predictors that are recognized as players shaping the decision-making to prefer a specific arsenic-mitigation technology[25,26]. For the current study, we applied the Binary Logistic Regression Model (BLRM) technique, as the responses were dichotomous[22,26,27]. In BLRM, the response is called a logit (L_i), which is a log of odds for two different groups that offer predicted probabilities that are limited to an assigned binary, in this study between 0 (No) and 1 (Yes)[22,26,27]. The general form of logistic regression is as follows

$$L_i = B_o + B_1 X_1 + \cdots + B_k X_k,$$

where $X_1,\ldots, X_k$ are explanatory variables and scores for the L_i are a linear combination function of the scores on one or several predictors[21,22,25,26]. The parameters $B_1,\ldots,B_k$ are the regression coefficients associated with predictors that represent the nature and the strength of the association of each predictor[21,22,25,26]. Therefore, L_i is a function of the predicted probability (P_i) according to

$$L_i = \ln\left[\frac{\hat{P}_i}{1+\hat{P}_i}\right].$$

Given a value of L_i, we can derive the corresponding value of $\hat{P}_i$ from

$$P_i = \frac{e^{L_i}}{1+e^{L_i}},$$

where P_i is the probability of opting for a specific arsenic-mitigation technology as a source of arsenic-free drinking water in the surveyed villages.

BLRM offers several methods for step-wise selection of the best predictors to include in the model. In the SPSS environment, BLRM starts with a model without considering any predictors, and at each consecutive step, the predictor with the greater statistical score with a P value more than 0.100 and significant at the specified value of 95% confidence interval ($P < 0.05$) is added to the model[21,25,28]. Furthermore, only the variables with a coefficient statistically different from zero (null hypothesis) and significant at 95% confidence interval are retained in the model[21,25]. The statistical significance test about the predictive usefulness of each predictor used the Wald χ^2 value at a 95% confidence interval for the corresponding degree of freedom[21,25]. Both the enter and step-wise forward conditional methods were applied to fit the model. Here, the results from the step-wise forward conditional method are presented, as the enter method did not produce any additional predictors, which contributed significantly to the model[22].

BLRM produces a pseudo R^2 value to assess the overall goodness of fit, and indicates how the logit model fits the data set. The pseudo R^2 value is derived from the following equation and a value greater than 0.2 is considered to be a good fit[25].

$$\text{pseudo}R^2 = 1-[(-2\log \text{likelihood}_{\text{final step}})/ (-2\log \text{likelihood}_{\text{initial step}})].$$

Additionally, to explain the percentage of variance of the response by the predictors, Cox and Snell R^2 and Nagelkerke's R^2 are produced[21,25,28]. Considering the categorical nature of the variables, a contingency analysis was performed on each of the selected variables versus the response variable, which was arsenic-mitigation preferences in this case[22,26]. Only significant independent variables were retained to create BLRM. To avoid any possibility of impact of multicollinearity on the predictability performance of BLRM, 'tolerance' and 'variance inflation factor' (VIF) tests were performed[21,22,25,26,28]. Furthermore, the threshold value of 0.1 for tolerance and 10 for VIF were followed to retain the predictors for the analysis. Therefore, predictors with tolerance >0.1 and VIF <10 were retained for BLRM[21,22,25,26,28].

Results

Household characteristics of the surveyed population

The details of the survey results are explained elsewhere[6]. Here we only present the summary of the findings relevant to this study. The majority of respondents was male (95%), as women in rural areas hesitate to interact with outsiders. The maximum participation in the survey was from backward castes (note 1), followed by forward castes (note 2) and scheduled castes (note 3), respectively[29–33]. A majority (94%) of the respondents were married, 6% had never been married, and one respondent was widowed. In terms of level of education, a total of 86% of the population had some level of education. However, the rest of the population (14%) was illiterate. Although the average literacy rate in the area was greater than the state's literacy rate of 35%, the majority of the population had only a primary level of education followed by a secondary and a college level of education, respectively. The average family size in the area was 6 persons per household. The largest proportion (37%) of the population was found to live in *kachcha* (note 4) houses followed by *pucca* (note 5) houses, thatched roof and straw made roof houses respectively. Altogether, a total of 33% of the population was found to be living in poorly constructed structures, mostly made up of straw or mud (Figure 2).

Housing status is generally associated with income. However, it was observed that a few respondents with higher income intentionally avoided better houses, as they wanted to hide or avoid exposing their income to villagers. The occupation of majority of the population was found to be either wage labour (39%) or agriculture (34%). A majority of respondents (71%) earned between Rs 500 and Rs 10,000 (just above the poverty line); 18% earned more than Rs.10,000 per month, and 11% earned below the poverty level with a monthly income less than Rs 500. Majority of the respondents (81%) reported that they defecate in open places, regardless of toilet availability. Only 19% of the population used toilets for defecation. It was surprising that the total sanitation campaign programme, the government of India's most ambitious programme to accomplish one of the millennium development goals, had almost no impact on sanitation practices in the surveyed population.

The χ^2 test between the demographic variables and the three surveyed villages revealed that gender ($P = 0.038$), age ($P = 0.049$), caste (note 6) ($P < 0.001$), marital status ($P = 0.015$), education level ($P < 0.001$), occupation ($P < 0.001$), income ($P < 0.001$), agricultural landholdings ($P = 0.023$), and housing status ($P = 0.001$) of the respondents were all significantly different in the three surveyed villages.

Status of water and sanitation of the surveyed population

The number of family members involved in water collection ($P = 0.017$), time spent per day for collection of water ($P = 0.001$), distance travelled to collect water ($P < 0.001$), place for defecation ($P < 0.001$), and materials used for hand washing ($P < 0.001$) were significantly different in the three surveyed villages (Table 1).

Figure 2. A house in good condition constructed of straw and mud in the villages (photograph by Sushant Singh, 2013).

Moreover, the sources used for drinking ($P < 0.001$), cooking ($P < 0.001$), and bathing ($P < 0.001$) water were significantly different across the three surveyed villages. However, the source used for irrigation was the same in surveyed villages as the communities used the only one source, borewell for irrigation purposes ($P = 0.314$; Table 2).

Social capital

The presence and functionality of institutions in the surveyed villages including Anganwadi (note 7) ($P = 0.001$), Mahila Samakhya (note 8) ($P < 0.001$), and self-help group ($P < 0.001$) were found to be significantly different among the villages[34–36] (Table 3). Moreover, respondents' individual social capital (determined as their neighbours and other people seeking their advice and valuing their opinion) was significantly different ($P = 0.008$) in the surveyed villages (Table 3).

Trust in others and in institutions

Respondents' trust in other members of the community outside their family ($P < 0.001$), trust in government agencies ($P < 0.001$), NGOs ($P < 0.001$), private agencies ($P < 0.001$), and trust in academics/scientists ($P < 0.001$) were significantly different in the surveyed villages. However, trust in Panchayati Raj Institutions (note 10) in the three villages was not different[37,38] ($P = 0.059$; Table 4).

Willingness to pay for arsenic-free water

The majority of the respondents was willing to pay for arsenic-free water to a lesser (<Rs 25) or greater extent (>Rs 50), with only 4% of the participants showing no willingness to pay for arsenic-free water (Table 5). Willingness to pay for arsenic-free drinking water among the respondents in the surveyed villages was significantly different ($P < 0.001$; Table 5).

Awareness about arsenic and associated issues

The majority of individuals was either not aware of arsenic-related issues or had low awareness (Table 6). Only 4% of the respondents scored high awareness to arsenic issues in the area (Table 6). Based on the χ^2, knowledge and awareness about arsenic and associated health risks were significantly different in the surveyed villages ($P = 0.016$; Table 6).

Table 1. Water and sanitation status in the surveyed villages

Variables	Percentage	χ^2 significance
Number of family members involved in water collection (*n* = 340)		
≤5 people	56	0.017
>5–10>	42	
>10	2	
Time spent, per day for collection of water (*n* = 339)		
<10 min	87	0.001
>10 min	13	
Distance travelled to collect water (*n* = 340)		
<50 m	88	0.001
>50 m	12	
Sanitation status/place for defecation (*n* = 340)		
Open field	81	<0.001
Toilet	19	
Hand-washing after defecation (*n* = 340)		
Soil	87	<0.001
Soap/ash	13	

Table 2. Sources of water for drinking, cooking, bathing, and irrigation

Uses of water	PvT (%)	PbT (%)	PvHP (%)	PbHP (%)	Boring (%)	DW (%)	χ^2 significance
Drinking	1.8	1.2	46.2	49.4	0.3	1.2	<0.001
Cooking	1.2	1.2	45.6	50.6	0.3	1.2	<0.001
Bathing	1.2	1.2	44.4	51.8	0.3	1.2	<0.001
Irrigation	0.0	0.0	0.3	0.3	58.5	0.0	0.314

PvT, private tap; Pbt, public tap; PvHP, private hand pump; PbHP, public hand pump; DW, dug well/open well.

Table 3. Social capital in the surveyed villages

Social capital-questions asked	Response	Percentage	χ^2 significance
Opinion about the presence and the functionality of Anganwadi (*n* = 340)	Not available[#]	1	0.001
	Strongly disagree	31	
	Neutral	7	
	Strongly agree	62	
Opinion about the presence and the functionality of Mahila samakhya (*n* = 340)	Not available	43	<0.001
	Strongly disagree	29	
	Neutral	12	
	Strongly agree	16	
Opinion about the presence and the functionality of self-help group (*n* = 340)	Not available	47	<0.001
	Strongly disagree	28	
	Neutral	7	
	Strongly agree	18	
Participation in panchayat activities (*n* = 340)	Strongly disagree	7	
	Neutral	3	
	Strongly agree	90	
Neighbours and others seeking advice and valuing respondents' opinion (*n* = 339)	Strongly disagree	25	0.008
	Neutral	10	
	Strongly agree	65	

[#]Not available, Not available within the village.

People's preference for arsenic-mitigation technologies

A majority of the population preferred arsenic treatment units (39%) as a convenient and sustainable source of arsenic-free water, followed by piped water supply (36%), deep tube wells (11%), and dug wells/open wells (10%). Only four respondents (1%) preferred rainwater harvesting systems as a convenient and sustainable arsenic-mitigation technology (Figure 3). Preferences for arsenic treatment units, deep tube wells, dug wells/open wells, piped water supply and rainwater harvesting systems by

Table 4. Trust in others and in institutions in the surveyed villages

Trust-questions asked	Response	Percentage	χ^2 significance
Trust in people outside family (n = 340)	None	4	<0.01
	1 to 5	68	
	>5	28	
Trust in government agencies (n = 340)	Strongly disagree	9	<0.001
	Neutral	2	
	Strongly agree	89	
Trust in NGOs (n = 335)	Strongly disagree	50	<0.001
	Neutral	18	
	Strongly agree	31	
Trust in Panchayati Raj Institutions (n = 340)	Strongly disagree	15	0.059
	Neutral	5	
	Strongly agree	80	
Trust in private agencies (n = 331)	Strongly disagree	66	
	Neutral	15	
	Strongly agree	17	
Trust in academics/scientists (n = 339)	Strongly disagree	8	<0.001
	Neutral	2	
	Strongly agree	90	

Table 5. Willingness to pay for arsenic-free drinking water

Willingness to pay for arsenic-free drinking water (n = 340)	Percentage	χ^2 significance
None	4	<0.001
<Rs 25 per month	56	
>Rs 50 per month	40	

Table 6. Awareness about arsenic and associated issues in the surveyed villages

Awareness about arsenic and associated issues (n = 340)	Percentage	χ^2 significance
No awareness	36	0.016
Low awareness	60	
High awareness	4	

the respondents were significantly different ($P < 0.001$) across the three surveyed villages (Figure 3).

Most preferred arsenic-mitigation technologies: arsenic filtration units and piped water supply systems

Providing arsenic treatment units could help reduce health risks of the population exposed to arsenic through drinking water to at least 39%, in the surveyed communities. An arsenic-mitigation plan could be designed, emphasizing provisions of arsenic treatment units in villages. However, lessons learned from other studies should be incorporated in any mitigation policy before implementing it for the benefit of the at-risk population. For instance, in a recent feasibility study of a popular sono arsenic-filter, the authors found that about 28% of the tested filters were abandoned because of the repair cost, maintenance problems, lack of guidelines for sludge-disposal, and slow flow rate. The implementation approach suffered from a serious lack of ownership[15,39]. Since a majority of the communities in this study were found to be willing to pay less than Rs 25, followed by >Rs 25, amounting up to Rs 500 per month, arsenic treatment units with an initial investment of Rs 25 per month could solve the arsenic problem of at least 56% of the population in the area. Furthermore, arsenic treatment units that require more than Rs 25 per month with a maximum limit of Rs 100 could improve the lives of 40% of the surveyed population. Moreover, it is advisable that pictorial instruction manuals for arsenic treatment units be provided to the beneficiaries with proper training to operate and maintain the units. The communities need easy access to the replacement parts of arsenic treatment units. For example, in this study we found that a newly installed arsenic removal unit was defunct as a consequence of installation in an inappropriate site, followed by nonavailability of resources for minor repairs and nonavailability of technical experts (Figure 4).

Piped water supply was found to be the second most preferred arsenic-mitigation technology in the area. The government of India has initiated projects to provide arsenic-free water in 120 villages in the MGP (ref. 1). However, the operation and maintenance costs and the corruption involved in setting up and establishing such systems are issues of serious concern, as reported earlier in the literature[15,16]. The respondents in this study expressed similar concerns.

Least preferred arsenic-mitigation technologies: deep tube wells, dug wells, and rainwater harvesting systems

Only 11% of the population preferred deep tube wells as a convenient and feasible arsenic-mitigation technology in the area. Deep tube wells are usually installed by a government agency as arsenic-free drinking water sources (Figure 5). The low preference for deep tube wells could be due to known arsenic contamination in the existing deep tube wells in the villages, their location on private property, or known technical difficulties with existing deep tube wells.

There is no one who is formally responsible for maintaining these deep tube wells. When these units fail, there is a lack of willingness to fix them or to contact the PHED engineers, leading to the abandonment of the units. This observation is in line with several studies where community-based arsenic-free water sources were found to be nonfunctional[15]. Moreover, identifying arsenic-free deep aquifers in which to install deep tube wells is another challenge, as the spatial distribution of arsenic in the groundwater in the MGP is highly variable. Additionally, high installation costs, and interference from other contaminants (for example high concentrations of iron, fluoride, nitrate, and salts) are some of the major constraints in the successful installation and continuous use of deep tube wells[10,40].

Long-term quality of targeted groundwater sources accessed by deep tube wells is not clear. For example, Ravenscroft *et al.*[41] reported that there is no evidence of deterioration of groundwater quality over a period of more than a decade. On the other hand, it was also reported that over-exploitation of deep aquifers might lead to contamination from the downward movement of water

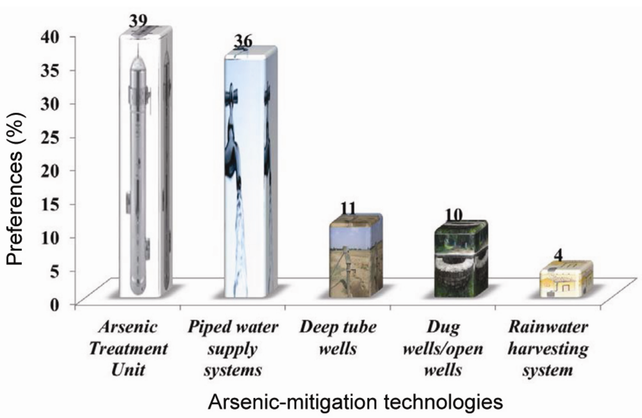

Figure 3. Arsenic-mitigation preferences in the surveyed villages. Sources for graphics: http://www.supplyhouse.com/Aqua-Pure-Water-Filters-11900000; http://www.drfranklipman.com/why-you-simply-must-filter-your-water/

Figure 5. A typical deep tube well installed by the state government (photograph by Sushant Singh, 2013).

Figure 4. Nonfunctional arsenic-removal unit in Bhawani Tola (photograph by Sushant Singh, 2013).

Figure 6. An abandoned arsenic-free open dug well in Rampur Diara, Maner, Patna, Bihar, India (photograph by Sushant Singh, 2013).

from shallow arsenic-contaminated aquifers[42]. Deep tube well units require regular monitoring, as leakage from the shallow aquifers to the deep aquifers and construction deformities in the installed deep tube wells units could cause arsenic-contamination of the deep aquifers[43]. Therefore, communities must take responsibility for appropriate use and maintenance of deep tube wells. Assistance from trained masons and access to replacement parts would significantly promote the sustainable use of deep tube wells in the villages and improve the lives of at-risk populations.

Dug wells, usually 10 to 20 m deep, are arsenic-free, or in some cases, have arsenic levels below the WHO standards of 10 μg/l in the MGP[4,40]. About 10% of the respondents reported that dug wells/open wells could be a convenient and feasible option for arsenic-free water in their localities. Dug wells are a traditional way of extracting groundwater in rural India. A switch from surface water extraction to groundwater extraction led to the abandonment of these wells. The communities in the study area showed interest in renovating and maintaining the abandoned dug wells, provided the costs are covered by the government or other agencies.

In most circumstances, the owners of dug wells on private property were willing to share water with their neighbours and others in need. A couple of renovated and newly constructed dug wells were found in the area, but all were defunct (Figure 6). Most of the abandoned dug wells were in good condition and they could be renovated with small investments. However, the probability of bacterial contamination could be one of the major hindrances in the success of dug wells, as reported in newly constructed wells in West Bengal[44]. The surveyed villages experience floods almost every year because of river Ganga or river Sone. Therefore, the likelihood of bacterial contamination in deep tube wells and dug wells is very high. Villagers reported that most of the hand pumps yielded dirty water after the floods in July 2013. Therefore, regular chlorination is required to prevent bacterial contamination in newly renovated dug wells[44].

Only 1% of the population reported that a rainwater harvesting system could be a convenient and feasible source of arsenic-free water. A few rainwater harvesting units have been installed in the surveyed villages. Although rainwater harvesting unit was installed in a school, the villagers reported that it had never been used since installation. High installation costs, lack of adequate rainfall of about 1600 mm/year or more, and need for regular maintenance to maintain system hygiene and avoid external contamination are some of the major challenges associated with this option[45–47]. About 78% of the surveyed population lacked proper housing with concrete roofs necessary to support the rainwater harvesting components. Therefore, rainwater harvesting does not seem to be a good fit for such communities, as evidenced by their minimal response in preferring this option as a convenient and feasible alternative of arsenic-free water. Also, it could be because of lack of knowledge or failure of rainwater harvesting systems in the neighbouring village (Rampur Diara).

Binary logistic regression model of arsenic treatment units

Based on the contingency analysis, a total of 19 independent variables were found to be statistically significant and were recruited to fit the model. All the selected predictors did not show multicollinearity as the tolerance and the VIF values were within the acceptable range of >0.1 and <10 respectively.

The probability of the full model χ^2 (183.983) was $P < 0.001$. Therefore, the full predictive model with all the independent variables, predicts the odds of selecting arsenic treatment units as a convenient and feasible arsenic-mitigation technology, and was found to be significantly better than a null model that does not include any predictor[26]. Ratios of valid cases to independent variables (41/1) were found to be satisfactory at the minimum ratio of 10/1 (ref. 22). The strength of the association between arsenic awareness index, willingness to pay for arsenic-free water, opinion about the presence and functionality of Mahila Samakhya, trust in people, trust in government agencies, NGOs, and private agencies, respondents' social capital (people seeking their advice and valuing their opinion), and preference for arsenic treatment unit as a feasible and convenient source of arsenic-free water were relatively strong with Cox and Snell's $R^2 = 0.429$ and Nagelkerke's $R^2 = 0.585$ (Table 7). The pseudo R^2 value (0.334) was found to be greater than the set value of 0.2, which indicates a relatively good fit[25]. Among all the predictors, trust in people was found to be the most important predictor, as it was the first selected independent variable in the model.

From BLRM, no awareness (OR = 0.110, $P = 0.009$) or low awareness (OR = 0.107, $P = 0.009$) of arsenic and associated health issues among the surveyed respondents placed the communities at lower odds of preferring arsenic treatment units as a convenient and feasible arsenic-mitigation technology. Specifically, the respondents with a higher arsenic awareness index were about 9 and 9.3 times more likely to prefer arsenic treatment units than communities with no awareness or low awareness, respectively. Respondents with the WTP of <Rs 25 (OR = 3.6, $P = 0.293$) and the WTP of >Rs 25 (OR = 11.348, $P = 0.053$) for arsenic-free water were 3.6 to 11.3 times more likely to prefer arsenic treatment units than people with no WTP for arsenic-free water. People who responded that Mahila Samakhya is either not available (OR = 3.3, $P = 0.025$), not functioning (OR = 3.6, $P = 0.008$), or who showed a neutral response (OR = 7.1, $P = 0.001$) were 3.3 to 7.1 times more likely to prefer

Table 7. Binary logistic regression model of arsenic treatment units

Variables	Reference category	*P* value	OR	CI Lower	CI Upper
Arsenic awareness index	High awareness	0.019			
No awareness		0.009	0.110	0.021	0.574
Low awareness		0.005	0.107	0.022	0.509
Willingness to pay for arsenic-free water	None	0.002			
<Rs 25		0.293	3.693	0.324	42.137
>Rs 25		0.053	11.348	0.972	132.432
Opinion about presence and functionality of Mahila Samakhya	Strongly agree	0.010			
Not available		0.025	3.350	1.166	9.625
Strongly disagree		0.008	3.630	1.392	9.469
Neutral		0.001	7.170	2.157	23.834
Trust in people	>5 people	0.000			
None		0.856	0.843	0.132	5.367
1 to 5 people		0.000	8.080	3.057	21.357
Trust in governmental agencies	Strongly agree	0.004			
Strongly disagree		0.001	0.055	0.010	0.309
Neutral		0.528	0.545	0.083	3.584
Trust in NGOs	Strongly agree	0.027			
Strongly disagree		0.011	3.609	1.349	9.653
Neutral		0.021	4.940	1.279	19.085
Trust in private agencies	Strongly agree	0.01			
Strongly disagree		0.003	9.000	2.090	38.753
Neutral		0.069	4.766	0.887	25.602
Neighbours and others seeking advice and valuing opinion	Strongly agree	0.000			
Strongly disagree		0.000	4.779	2.067	11.05
Neutral		0.002	7.227	2.007	26.027

Cox & Snell $R^2 = 0.429$; Nagelkerke's $R^2 = 0.586$; Pseudo $R^2 = 0.334$.

arsenic treatment units than people who strongly agreed with the presence and functionality of Mahila Samakhya in the villages.

Respondents who trust 1 to 5 people outside their family (OR= 8 .0, $P < 0.001$) were 8 times more likely to prefer arsenic treatment units than communities which reported higher trust in others. The communities which had no trust in government agencies (OR = 0.055, $P = 0.001$) were less likely to prefer arsenic treatment units than people with trust in government agencies. In other words, respondents with trust in government agencies were 18 times more likely to prefer arsenic treatment units than those with no trust. However, those who had no trust in either NGOs (OR = 3.6, $P = 0.011$) or private agencies (OR = 9.0, $P = 0.003$) were respectively, 3.6 and 9 times more likely to prefer arsenic treatment units than people with higher level of trust in these agencies. Respondents with lower social capital (e.g. their neighbours do not seek their advice or value their views), (OR = 4.7, $P < 0.001$) were 4.7 times more likely to prefer arsenic treatment units than those with higher social capital.

The predicted accuracy for selecting arsenic treatment units was 69%, and 86.8% for not choosing arsenic treatment units, with an overall predicted accuracy of 80.2%. The criterion for classification accuracy was satisfactory, as it is greater than proportional by chance accuracy criteria of 25%. Values from sensitivity and specificity tests were higher (0.87 and 0.69)[26]. This further explains that the independent variables included in the model could be characterized as useful predictors and the logistic regression model was a good fit.

Binary logistic regression model of piped water supply systems

In the BLRM of piped water supply, a total of nine variables were found to be statistically significant and recruited to fit the model. The predictors included in the model did not show multicollinearity as the tolerance and VIF values were within the acceptable range of >0.1 and <10 respectively.

The probability of the model χ^2 (145.214) was $P < 0.001$. Therefore, the full predictive model with all independent variables predicts the odds of selecting piped water supply as a convenient and feasible

Table 8. Binary logistic regression model of piped water supply

Variables	Reference category	*P* Value	OR	CI	
				Lower	Upper
Caste	Forward caste	0.008			
Scheduled caste		0.147	0.394	0.112	1.387
Backward caste		0.002	0.229	0.118	0.620
Occupation	Job/Business	0.014			
Unemployed		0.034	4.432	1.122	17.502
Labour		0.013	3.597	1.317	9.823
Agriculture		0.923	0.959	0.406	2.264
Hand washing	Soap/Ash	0.033			
Soil			0.353	0.135	0.920
Willingness to pay for arsenic-free water	None	0.004			
<Rs 25		0.818	0.845	0.200	3.559
>Rs 25		0.083	0.258	0.056	1.193
Opinion about the presence and functionality of Anganwadi	Strongly agree	0.044			
Not available		0.955	1.098	0.043	28.148
Strongly disagree		0.005	2.742	1.366	5.505
Neutral		0.455	1.532	0.500	4.696
Opinion about the presence and functionality of self-help group	Strongly agree	0.000			
Not available		0.000	6.669	2.663	16.705
Strongly disagree		0.255	1.816	0.649	5.080
Neutral		0.010	5.687	1.504	21.506
Trust in people	>5 people	0.053			
None		0.566	0.662	0.162	2.706
1 to 5 people		0.017	0.407	0.195	0.849
People seeking advice and valuing opinion	Strongly agree	0.000			
Strongly disagree		0.001	0.261	0.118	0.578
Neutral		0.003	0.139	0.037	0.519

Cox & Snell $R^2 = 0.415$; Nagelkerke's $R^2 = 0.566$; Pseudo $R^2 = 0.324$.

arsenic-mitigation technology significantly better than a null model that does not include any predictors[26]. Ratios of valid cases to independent variables (37/1) were found to be satisfactory at the minimum ratio of 10/1 (ref. 22). The strength of the association between gender, caste, sanitation habits (hand washing), WTP for arsenic-free water, opinion about the presence and functionality of Anganwadi and self-help group, trust in people, and respondents' social capital (determined as people seeking their advice and valuing their opinion) and preference for piped water supply as a feasible and convenient source of arsenic-free water were moderately stronger with Cox and Snell's $R^2 = 0.415$ and Nagelkerke's $R^2 = 0.566$ (Table 8). The pseudo R^2 value (0.324) was found to be greater than the set value of 0.2, which indicates a relatively good fit[25]. Among all the predictors, caste was found to be the most important predictor, as it was the first selected independent variable in the model. The backward caste respondents were less likely (OR = 0.27, $P = 0.002$) to prefer piped water supply systems than the forward caste respondents. Precisely, the forward caste communities were thrice more likely to prefer piped water supply than backward caste population (Table 8).

The communities with no education (OR = 0.042, $P < 0.001$), primary education (PR = 0.571, $P = 0.299$), and secondary education (OR = 0.382, $P = 0.085$) were less likely to prefer piped water supply than respondents with college degrees. People who were unemployed (OR = 5.6, $P = 0.032$) or worked as daily wage labourers (OR = 6.8, $P = 0.001$) were respectively 5.6 and 6.8 times more likely to prefer piped water supply than people who had a job or owned a business for their livelihood. As expected, the communities living in straw houses (OR = 0.047, $P = 0.008$) were less likely to prefer piped water supply than respondents living in *pucca houses*. People with no willingness to pay for arsenic-free water were more likely to prefer piped water supply than people with low (OR = 0.835, $P = 0.814$) or higher willingness to pay (OR = 0.274, $P = 0.110$). Respondents who strongly disagreed (OR = 3.3, $P = 0.002$) with the presence and functionality of Anganwadi were 3.3 times more likely to prefer piped water supply than people who supported Anganwadi. Moreover, people who reported that there was no self-help group (OR = 8.4, $P < 0.001$) in the area or were neutral (OR = 6.1, $P = 0.011$) were 8.4 and 6 times more likely to prefer piped water supply than

Table 9. Binary logistic regression model of deep tube wells

Variables	Reference category	*P* Value	OR	CI Lower	CI Upper
Age		0.008	1.039	1.010	1.068
Time spent for water collection	>10 min	0.000			
<10 min			0.166	0.061	0.455
Willingness to pay for arsenic-free water	None	0.0310			
<Rs 25		0.770	1.286	0.239	6.930
>Rs 25		0.243	0.343	0.057	2.072
Opinion about presence and functionality of Mahila Samakhya	Strongly agree	0.001			
Not available		0.000	0.120	0.041	0.349
Strongly disagree		0.005	0.224	0.079	0.639
Neutral		0.997	0	0	.

Cox & Snell $R^2 = 0.199$; Nagelkerke's $R^2 = 0.388$; Pseudo $R^2 = 0.2$.

respondents who strongly agreed with the presence and functionality of self-help group. People with a higher level of trust (OR = 0.36, $P = 0.010$) in their neighbours were 4% less likely to prefer piped water supply. Similarly, people with lower social capital (OR = 0.280, $P = 0.004$) were 2.8% less likely to prefer piped water supply than communities with higher social capital. In other words, it could be explained by the fact that communities with higher social capital were at least 3 times more likely to prefer piped water supply than those with no social capital, or those who had a neutral response, respectively (Table 8).

BLRM was able to predict 78.5% of the probability to prefer piped water supply, and 85% probability do not prefer piped water supply, with the overall prediction accuracy of 82.6%, which satisfies the criterion for classification accuracy. The sensitivity test (0.86) and the specificity test (0.67) produced a comparatively higher value[26]. This further explains that independent variables included in the model could be characterized as useful predictors and the logistic regression model has a good fit.

Binary logistic regression model of deep tube wells

In the BLRM of deep tube wells, a total of four variables were found to be statistically significant and were recruited to fit the model. The predictors included in the model did not show multicollinearity as the tolerance and VIF values were within the acceptable range of >0.1 and <10 respectively.

The probability of the model χ^2 (72.666) was $P < 0.001$. Therefore, the full predictive model with all independent variables, predicts the odds of selecting deep tube wells as a convenient and feasible arsenic-mitigation technology significantly better than a null model that does not include any predictors[26]. Ratios of valid cases to independent variables (82/1) were found to be satisfactory at the preferred ratio of 50/1 (ref. 22). The strength of the association between age, distance from water source, WTP for arsenic-free water, and opinion about the presence and functionality of Mahila Samakhya and preference for deep tube wells as a feasible and convenient source of arsenic-free water was relatively weaker with Cox and Snell's $R^2 = 0.199$ and Nagelkerke's $R^2 = 0.388$ (Table 9). The Pseudo R^2 value was found to be equal (0.2) to the set value of 0.2, which indicates that the data did not fit well[25]. After revisiting the frequency distribution for the response to deep tube wells, we found that only 10% of the respondents opted for deep tube wells. A possible explanation could be that a minimum percentage of positive response is needed to fit the logistic regression model with an appropriate sample size[23].

Among all the predictors, time spent collecting water was found to be the most important predictor as it was the first selected independent variable in the model. The likelihood of selecting deep tube wells in all the age groups (OR = 1.0, $P = 0.008$) was equal in the communities. The respondents who spent less than 10 min per day collecting water (OR = 0.165, $P < 0.001$) were less likely to select deep tube wells than people who devoted more than 10 min per day. In other words, the communities that devoted more than 10 min per day collecting water were at least 5 times more likely to choose deep tube wells than communities which spent less than 10 min per day collecting water. Respondents with no WTP for arsenic-free water were more likely to prefer deep tube wells than people with WTP > Rs 25 (OR = 0.287, $P = 0.176$) for arsenic-free water. However, the likelihood to select deep tube wells was equal amongst the communities with no WTP and WTP < Rs 25 (OR = 1.0, $P = 0.987$). People who responded that Mahila Samakhya is either not available (OR = 0.143, $P < 0.001$) or not functioning (OR = 0.249, $P = 0.01$) were less likely to prefer deep tube wells than people who strongly agreed with the presence and functionality of Mahila Samakhya (Table 9).

BLRM was able to predict only 36.8% of the odds of selecting deep tube wells. The prediction for not selecting deep tubes wells was 98%, and the overall prediction rate was 91%. The criterion for classification accuracy was

Table 10. Binary logistic regression model of dug wells/open wells

				CI	
Variables	Reference category	*P* Value	OR	Lower	Upper
Gender	Male	0.048			
Female			4.102	1.011	16.644
Income group	Upper APL	<0.001			
Below the poverty line		0.001	9.929	2.526	39.034
Above the poverty line		0.785	0.855	0.280	2.629
Opinion about presence and functionality of self-help group	Strongly agree	0.012			
Not available		0.005	0.239	0.089	0.645
Strongly agree		0.009	0.202	0.061	0.677
Neutral		0.504	0.555	0.098	3.126
Trust in people	>5	0.000			
None		0.837	1.193	0.222	6.409
1 to 5 people		0.000	0.164	0.066	0.410

less than proportional by chance accuracy criteria of 25%. Therefore, the model did not predict the odds well. The sensitivity test had a higher value (0.98). However, the specificity test produced a comparatively lower value (0.37)[26].

Binary logistic regression model of dug wells/open wells

In the BLRM of dug wells/open wells, a total of four variables were found to be statistically significant and were recruited to fit the model. The predictors included in the model did not show multicollinearity as the tolerance and the VIF values were within the acceptable range of >0.1 and <10 respectively.

The probability of the model χ^2 (54.214) was $P < 0.001$. Therefore, the full predictive model with all the independent variables, predicts the odds of selecting dug wells as a convenient and feasible arsenic-mitigation technology significantly better than a null model[26]. Ratios of valid cases to independent variables (83/1) were found to be satisfactory at the preferred ratio of 50/1 (ref. 22). The strength of the association between gender, income group, opinion about the presence and functionality of self-help groups, trust in people and preference for dug wells as a feasible and convenient source of arsenic-free water was relatively weaker with Cox and Snell's $R^2 = 0.164$ and Nagelkerke's $R^2 = 0.333$ (Table 10). The derived pseudo R^2 value was (0.175) found to be less than the set value of 0.2, which indicates a relatively poor fit[25]. Among all the predictors, income group was found to be the most important predictor as it was the first selected independent variable in the model. Women (OR = 4.1, $P = 0.048$) were 4.1 times more likely to prefer dug wells as a convenient and feasible source of arsenic-free water than men. Respondents living below the poverty line with monthly cash income less than Rs 500 (OR = 9.9, $P = 0.001$) were 9.9 times more likely to prefer dug wells than those who were earning more than Rs 10,000 per month. However, people who reported that self-help groups are not available in the villages (OR= 0 .24, $P = 0.005$) or did not agree about the presence and functionality of self-help groups (OR = 0.20, $P = 0.009$) in the area were less likely to prefer dug wells than people who strongly agreed about the presence and functionality of self-help groups in the project area. Moreover, people with moderate trust (1 to 5 people) in their neighbours (OR = 0.164, $P < 0.001$) were less likely to prefer dug wells than people with a high level of trust (>5 people) in others (Table 10).

Similar to the BLRM of deep tube wells, the BLRM of dug wells was able to predict only 34% of the probability to select dug wells, with 99% not opting for dug wells, leading to an overall accuracy of 92.4%. Therefore, the criterion for classification accuracy was found to be less than the proportional by chance accuracy criteria of 25%. The sensitivity test reached the maximum level (1). However, the specificity test produced a comparatively lower value (0.31)[26]. After revisiting the frequency distribution for the response for dug wells, we found that only 10% of the respondents preferred dug wells as a convenient and feasible source of arsenic-free water. A possible explanation could be that we could not get the minimum required percentage of positive responses to fit a logistic regression model with an appropriate sample size[23].

Conclusion

A majority of the surveyed respondents could be characterized as marginalized. A quarter of the population was illiterate. More than 62% of the population had a larger than average household size. More than 80% of the population had no proper job and were either unemployed, engaged in daily wage labour, or were dependent on agriculture for their livelihood. About 70% of the population lived in sub-standard housing.

Based on contingency analysis, gender, age, education level, income, occupation, housing status, time spent collecting water, distance travelled to collect water, WTP for arsenic-free sources, and awareness about arsenic and associated issues were found to be significant variables, which is in line with the previous studies[15,16]. It is important to mention here that only 17 female respondents participated in the current survey. Therefore, to draw a clear conclusion on the role of gender in the preference for arsenic-mitigation technologies would be over promising. However, this is the first study that offers insights that, beyond the regular socio-economic and demographic variables, there are other social factors including presence and functionality of institutions, trust in operating agencies in the areas, and people's trust in neighbours in the communities, which should be considered in future studies to evaluate acceptability of any arsenic-mitigation policy. Trust in people and WTP for arsenic-free water were found to be the common predictors in three models. However, social capital, presence and functionality of Mahila Samakhya, and presence and functionality of self-help groups were common predictors in at least two models.

The communities selected arsenic treatment units and piped water supply as the most convenient and feasible options in the villages. A mixed model of these two arsenic-mitigation options targeting poor, scheduled castes, and backward castes communities for arsenic treatment units and relatively affluent and/or forward castes communities could be an ideal arsenic-mitigation policy in the area. Along with these options, strengthening existing institutions, empowering agencies, and enlightening people about arsenic and associated problems are important. The respondents in all the three surveyed villages equally trust in government agencies. Therefore, government-led initiatives are most likely to be successful in these villages. Additionally, higher trust in Panchayat Raj Institutions and academics/scientists also suggest that the likelihood of success of initiatives led by these two agencies would be greater in these villages.

Notes

1. Backward caste: lower than the upper caste group that has been categorized as 'other backward classes' (OBCs) by constitutional provision. It consists of those castes which, like the 'scheduled castes', were in the past subjected to exclusions and, therefore, remained socially and educationally backward, despite having a higher position than 'scheduled castes' in the local, traditional caste hierarchy.
2. Forward caste: upper caste, at the top of the social stratification in Indian villages.
3. Scheduled caste: at the bottom of the social stratification, consists of those castes that were associated with the most impure work and menial labour with no possibility of upward mobility, and were subjected to serve social exclusion and disadvantages, in comparison to other castes.
4. Kachcha house: houses with temporary roofs made with cemented floor and/or wall.
5. Pucca house: houses with flooring, roof, and cemented walls.
6. System of rigid layering of society associated with the Hindu religion. An endogamous kinship group is the self-perceived 'caste' of the individual Hindu, or has been at least until relatively recent times.
7. Anganwadi (courtyard shelter) is a government of India's childcare and mother-care unit at Panchayat levels, comprised of mostly female health workers.
8. The Mahila Samakhya programme in rural Bihar is a women's literacy and education empowerment programme. The programme is aimed at women from the most disadvantaged socioeconomic groups.
9. A self-help group is a financial assistance group, based within the village, and is usually composed of 10–20 local women from the socio-economically deprived communities.
10. Panchayat Raj is a 'South Asian political system, mainly in India, Pakistan, and Nepal'. 'Panchayat' translates as 'assembly (ayat) of five (panch) wise and respected elders chosen and accepted by the village community'. 'Traditionally, these assemblies settled disputes between individuals and villages'.

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