Arsenic Testing of Newly Installed Tubewells and Quality Control

Md. Jakariya
Richard Johnstony
AMR Chowdhury

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BRAC, Research and Evaluation Division, 75 Mohakhali C/A, Dhaka 1212
Tel. 9881265, 884180, 884051, Fax. 880-2-883542, 883614,
email: bracamr@bdmail.net

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1. Executive summary

The presence of arsenic in groundwater in Bangladesh has aroused widespread concern. It is estimated that over half of the Bangladesh population are at risk of arsenic poising. The source of arsenic in drinking water is from the tubewells. There are over four million tubewells in Bangladesh. During 1997-1998, DPHE installed over 13,000 tubewells in a UNICEF supported Safe Water Supply Project. . At the request of UNICEF, BRAC test all the above mentioned tubewells for Arsenic contamination. In doing this, BRAC need a field kit and the quality of the testing was also assessed by simultaneous testing in a laboratory.

The proportion of tubewells with an arsenic content above the acceptable limit (=/< 50 ppb) was found to be 4.27% of 12,604 tubewells tested. Tubewells above the accepted limit were painted red , whereas those within the accepted limit were painted green by the field testers. The quality of testing by the field testers was found to be high and the effectiveness of the field kits was found to be adequate. DPHE have been relatively successful to avoid arsenic affected areas as the number of tubewells contaminated with arsenic above the acceptable limit was low.

The sub assistant engineers also mentioned that one of the main reasons for not installing all the allocated tubewells particularly in the arsenic affected areas was due to arsenic contamination in ground water.

Caretakers of each tubewell were given information on what to do if the tubewell tested arsenic contaminated. They were also given a leaflet provided by UNICEF containing information on arsenic and alternative safe water options.

2. Background

The discovery of arsenic in groundwater in several areas of Bangladesh has aroused widespread concern. In Bangladesh arsenic was first detected in 1993 at Baroghoria union of Chapai Nawabganj district. Since then, numerous organizations have conducted arsenic tests, with field kits and in laboratories, and contamination has been found to be quite extensive, affecting parts of most districts in the country. Approximately 25% of tubewells tested by the government to date have shown the presence of arsenic. Arsenic contamination has been detected in groundwater, and more commonly in the shallow aquifer (less than 50 meters deep). Since 97% of the population relies on groundwater for drinking purposes, nearly everyone living in affected areas is at risk of arsenic poisoning.

DPHE with UNICEF assistance is providing safe drinking water for the people of Bangladesh. In 1997-1998, DPHE installed over 13,000 tubewells in a UNICEF-supported Safe Water Supply Project. This project targeted unserved and underserved communities, where significant parts of the population do not have access to safe drinking water throughout the year. According to DPHE protocol, all newly installed tubewells must be tested for arsenic. However, due to supply constraints, field kits were not available to DPHE staff at the time of installation. When field kits were available, DPHE staff were heavily involved in repairing the devastation that followed the massive flooding of Fall

1998. In order to test all of the new tubewells in the quickest way possible and without compromising testing quality, UNICEF contracted BRAC to test the above mentioned new tubewells.

BRAC has experience in training community members in testing for arsenic and has completed an extensive type of testing program with the help of Village Health Workers (VHWs) at Hajiganj thana of Chandpur district. It is easy for BRAC to perform the same type of activity through its countrywide network with proper quality and management. In this way BRAC is contributing to solving the nationwide problem of arsenic contamination in the ground water.

3. Purpose of the Assignment

According to the Terms Of Reference prepared by UNICEF the purposes of the assignment were to

- test all the water supply points that were installed over the period 1997-1998 for arsenic using field test kits,
- ensure quality of the testing, and
- provide summary, computer database monthly updates and final report.

This assignment will contribute to the objective of providing safe drinking water for the arsenic affected populous of Bangladesh.

4. Testing of newly installed tubewells

4.1 Materials & Methods

Due to the scattered nature of the tubewells that needed testing the use of Community Village Health Workers in this instance would not have been viable. As a result 110 field researchers were trained centrally at BRAC HQ so as to ensure rapid testing. The quality of work was maintained by nine well trained supervisors who were involved during the whole testing period. The supervisors also checked whether all the tubewells tested were from the list provided by the local DPHE office and painted correctly (red for tubewells contaminated above the accepted limit and green for tube wells below the accepted limit). Finally the whole program was managed by a group of core researchers from BRAC head office. In addition to the testing of tubewell water the testers also collected information on the depth of tubewells, year of sinking, number of families using that particular tubewell, the total population of the village etc.

The field kit promoted by the National Institute of Preventive & Social Medicine (NIPSOM) in Dhaka was used for testing. This kit costs Tk. 900 and can test up to 100 water samples. It was claimed to be user friendly and able to detect arsenic concentration as low as 0.01 mg/L (Khan & Ahmed 1997).

The supervisors and field testers were given a two-day training in three phases on how to use field kits. They were also given some basic information on arsenic and

some of the short & long term remedial measures possible, so that they could advise villagers accordingly.
The whole study area was divided into nine different zones and each supervisor was given responsibility for one zone.

Village health workers and local BRAC and DPHE officials were consulted during testing when any problems arose.

4.2 Project observations and constraints

The supervisors and field testers made several observations and encountered certain limitations during testing. These consisted of :

- Unavailability of DPHE officials at their offices during the week days preventing the acquisition of the list of relevant tubewells installed during the above mentioned period.
- In many places lack of cooperation by DPHE officials in providing the necessary information. In many cases the number of tubewells in the list given by UNICEF was not similar to that given by the respective DPHE office.
- Incorrect information regarding the location of tubewells by the DPHE officials resulted in large amounts of time wasted by the field testers.
- DPHE offices in several thanas did not know the exact location of the un-specified tubewells given by UNICEF
- A number of tubewells were found to be out of order at the time of testing.
- Due to difficulties of heavy rocky soil in Patharghata thana and some areas of the greater Sylhet district, some of the allocated tubewells were not installed.
- Many people were unaware of the problems of arsenic poisoning. This was noted by two field investigators while working in Adhamdighi thana of Bogra district and the Chilmari thana of Kurigram district.
- There were incidences where field testers were prevented from painting tubewell heads due to perceived social and economical implications. For instance, in Keranigonj thana under the district of Dhaka, one individual thought that if the tubewell was painted red he would not be able to rent out his house. In the Sujanagar thana of Pabna district individuals from the 'the under ground activists', did not allow the tubewell head to be painted red as they thought that it would result in the area being known as a terrorist area.
- A number of patients showing symptoms of arsenic poisoning were unaware of the cause. They believed that it was a kind of skin disease. This was observed in Chilmari thana of Kurigram district and Sujanagar thana under Pabna district.
- In many places, particularly where the problem is severe, people were eager to

have their tubewell water tested. Although the location of the tubewells was very scattered this arsenic testing program remarkably increased arsenic awareness among rural communities.

- Tubewells owned by the public tended not to be adequately maintained. A good number of tubewells were found to be installed within the caretaker's homestead and in many places it was difficult to access these tubewells particularly in the more 'conservative' parts of the country.

4.3 Results

The total number of allocated tubewells during 1997 & 1998 based on information provided by UNICEF was 17,145. These tubewells are distributed in 317 thanas of 56 districts (detailed results are presented in the appendix). Information provided in the field by DPHE staff indicated that the number of tubewells installed was 13,442. The sub-assistant engineers mentioned that one of the main reasons for not installing all the allocated tubewells was due to arsenic contamination in groundwater.

A total of 12,559 tubewells were identified and tested by the field workers with field kits.

Table 1: Survey results at a glance

		% of wells tested
Number of districts	56	
Number of Thanas	317	
Number of districts with contaminated wells	37	
Number of thanas with contaminated wells	106	
Total number of allocated tubewells for the year '97-'98	17,145	
Total number of installed tubewells	13,442	
Total number of wells tested	12,599	
Total number of inactive tubewells	484	
Number of not identified tubewells	359	
Total number of tubewells with arsenic content less 50 ppb	12,078	96
Total number of tubewells with arsenic content =/> 50 ppb	521	4

The number of tubewells tested contaminated with arsenic more than the acceptable limit (i.e. =/> 50 ppb) was 521 i.e. 4% of the total tested (Table 1). The tubewells which showed arsenic concentration more than the acceptable limit were marked red, while the rest were marked green. A total of 484 of the installed tubewells were found to be inactive during the survey period. A breakdown of the distribution of wells contaminated with arsenic above and below the accepted level is given in appendices 2 &3.

Test result by tubewell type

The preliminary survey results revealed that 15 deep tubewells out of 536 contaminated tubewells were found to be contaminated with arsenic more than the acceptable limit of 0.05 mg/l. Therefore, an attempt was made to check all the 15 deep tubewells to confirm the absence of arsenic in the deeper aquifer. Following this recheck one deep tubewell situated at Companigonj was found to be contaminated with arsenic higher than the acceptable limit. Two others were found to be out of order. Here it is mentioned that maximum of the rechecked deep tubewells were found not completely arsenic free. This is obviously a matter of grave concern. Proper investigation into this must be taken immediately in order to keep this layer free from arsenic. Boring of more deep tubewells without putting any preventive measures to stop leaching of arsenic contaminated water from the shallow aquifer might aggravate the situation further.

Table : Different types of tubewells were tested under this project

Tubewell Type	Total No. of Tubewell	Arsenic Contaminated Tubewell
Shallow Tubewell	402	63
Tara pump (Standard Head)	6450	280
Tara Pump (6 no. Head)	2230	81
Deep Set	3090	3
SST/VSST	427	94

** Out of the 3 deep tubewells, one was found to be contaminated with arsenic, other two were found out of order.

4.4 Discussion

The objective of the study was to test all of the 13,442 tubewells installed by DPHE with UNICEF assistance (during the year 1997 & 1998). Using the NIPSOM field kit, the tested wells were marked red if contaminated with levels higher than the accepted limit and green if below that limit. Of the 13,442 installed tubewells, field workers were able to test 94% successfully, 3.6% were found to be inactive and the remaining 2.7% were not identified. Further investigation into why tubewells were inactive was not undertaken. In many cases it was reported by the local people that due to common ownership of the tubewell, no one user took responsibility to repair damaged tubewells. Rather, they just wait until DPHE mechanics come to repair it. The number of tubewells contaminated with arsenic above the acceptable limit (i.e. =/> 50 ppb) were found to be 521 (4% of the total tested). By minimizing the number of tubewells installed, DPHE has been successful in installing tubewells in selective arsenic contaminated areas.

5. Quality Control at field level

5.1 Method

A certain number of tube wells that had been tested by field staff were re-tested by the supervisors. At least three tubewells from each thana were re-tested using the same type of field kits and final results were matched with the field results centrally at BRAC head office.

5.2 Results of quality control

When regional supervisors visited newly installed tubewells, they did not know the results of the field kit test taken by the field tester. Since the field staff had painted the tubewell either red or green after testing, the supervisor had a general idea about the level of contamination, but the actual concentration reported was not known.

The supervisors made at least one field visit for each of the 120 field workers. Unfortunately, for about half of these visits, the exact location of the well was not recorded, and it was not possible to cross-reference test results with the original analysis conducted by the field staff. In 61 cases, this cross-reference was possible. **Figure 1** shows the correlation between field kit analyses conducted by field staff and regional supervisors.

The correlation is quite good, indicating that the field kits are robust and can give reasonably reproducible results, even when operated by different users. The good correlation further indicates that BRAC field staff were using the kits correctly, or at least in the same way as the regional supervisors.

In a few instances, the supervisor found significantly lower arsenic levels than the field staff. In one case, the supervisor found a well to be safe that the field worker had labeled unsafe. However, overall, the agreement between the field staff and supervisor analyses was excellent.

Fiqure 1: Field Level Qualitv Control

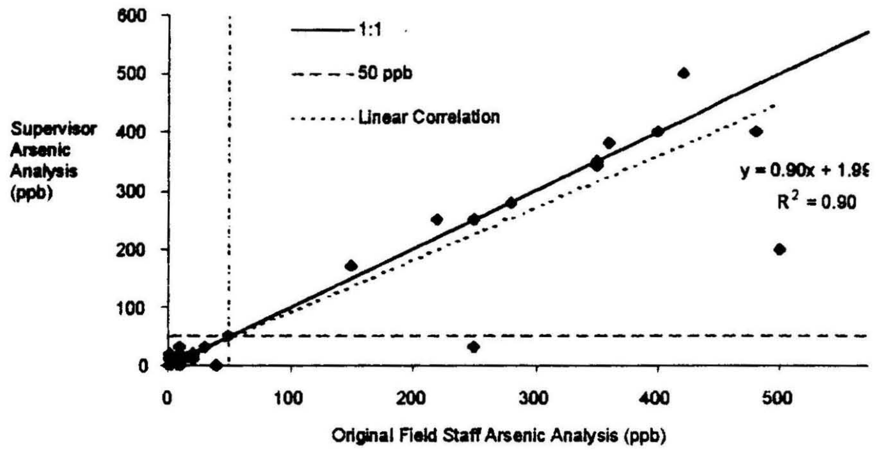

Figure 1 shows an excellent correlation between field kit analyses made by field staff and by supervisors.

6. Quality control at laboratory level

6.1 Method

176 water samples were selected randomly for further testing in the laboratory. The water samples were properly stored (i.e., acidified) before being sent for laboratory analysis by the 'Arsenator'. This new instrument has a quantification limit of 0.5 ppb, well below that of the *spectrophotometric method* widely used in laboratories in Bangladesh and comparable to, if not lower than, the limit for the atomic absorption method used in a handful of labs in Bangladesh.

Arsenators were operated by a handful of trained analysts, most under the supervision of Dr. Kosmus (University of Graz, Austria) who developed the arsenator.

While the Arsenator is an emerging technology which has not been tested outside of Dr. Kosmus' laboratory, it was chosen as the reference method in light of the great promise it shows for arsenic analysis. In addition, UNICEF had recently procured a number of the instruments, and was able to make use of these for the purpose of the quality control testing. During the testing, several sets of replicate analyses were made with the Arsenator, which gave very reproducible results. A more rigorous evaluation of the Arsenator is underway at present, in the most advanced laboratories of Bangladesh, which should clearly establish the accuracy and precision of this instrument.

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6.2 Result Samples Analyzed

As the field level quality control ensured that the field kits were being used correctly (or at least consistently) by the field staff, the laboratory level quality control had the objective of determining if the field kits provide accurate results when operated by field staff or supervisors. A total of 58 quality control samples were analyzed with the Arsenator. Several of these were analyzed repeatedly, in order to check the reproducibility of Arsenator analyses.

Field kit results ranged from below detection (10 ppb), to 500 ppb. All of the samples in the 20 - 200 ppb range were analyzed with Arsenators, as were most of the heavily contaminated samples (> 200 ppb). A subset of the NO DETECT samples were analyzed, as there were a large number of these. Efforts were made to select water quality samples from various parts of the country.

Figure 2: Field Test Kit versus Arsenator Results

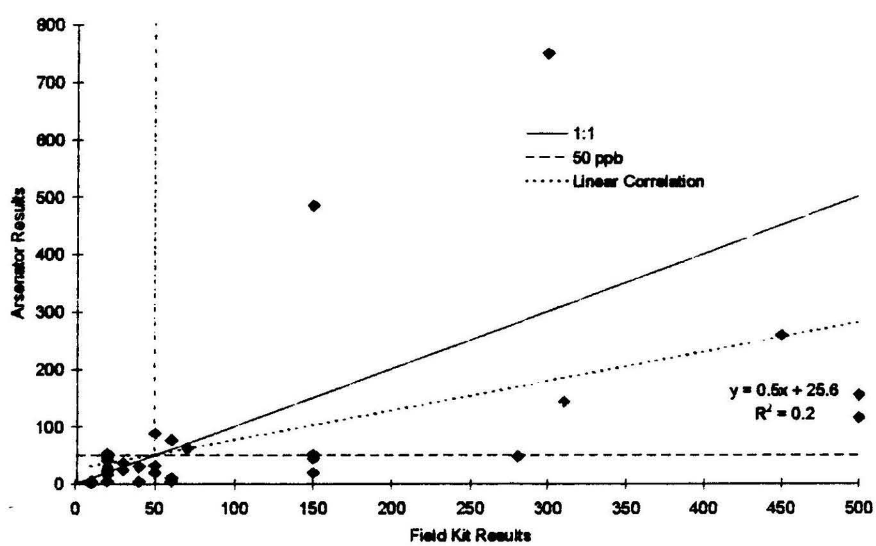

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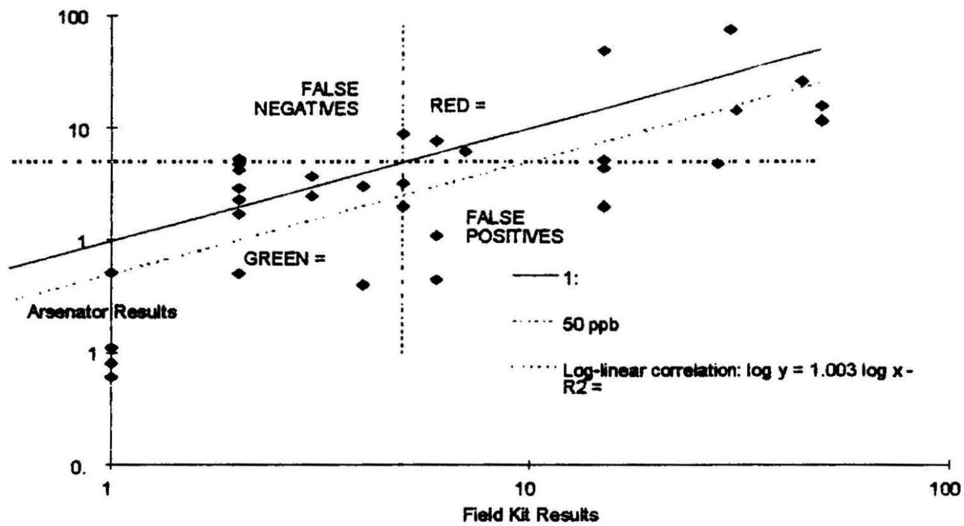
Figure 3: Field Test Kit versus Arsenator Results, log



While a positive correlation was found between field kit and Arsenator results, the field kit results were found to differ substantially from the Arsenator results. **Figure 2** shows the large amount of scatter between the two analyses. The same data are shown on logarithmic scales in **Figure 3.**

In general, the arsenic levels reported by the Arsenator were significantly lower than those reported by the field kits. This was surprising, as earlier reports had indicated that field kits were more likely subject to negative bias, or underestimation compared to more accurate methods. A breakdown of results is given in Appendix 4.

6.2.1 Quantitative Effectiveness of Field Kits

At a fully quantitative level, (i.e. the exact point level concentration of arsenic in water) the field kits are not very effective at all, as shown in **Figures 3 and 4**. Even if a generous tolerance of 50% is permitted[1], the fit between field kit and Arsenator analysis is poor. This is reflected in the very low R^2 shown in **Figure 3.**

Table 2: Quantitative Effectiveness of Field Kits

Range	# In range, by Arsenator	# Within 50%, by field kit	% Within 50%, by field kit

[1] *For example, if the Arsenator indicated 100 ppb arsenic, a field kit result of +/- 50%, from 50 to 150 ppb would be accepted.*

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< 10	31	27	87%
10 - 49	15	7	47%
50 - 199	9	3	33%
> 200	3	0	0%

Surprisingly, the field kits were seen to become less accurate at higher concentration.

Even more surprisingly, the field kits were found to overestimate arsenic levels, compared to Arsenator results, on average. This is seen in the slope of the regression curve in **Figure 3**, of about 0.5. This positive bias is seen more clearly in **Figure 4**, where many more points lie below the x=y line. The log-linear regression gives a much better fit, and yields an intercept of -0.3, which indicates that field kits, on average, gave results 2 times higher ($10^{0.306}$) than the Arsenator.

6.2.2 Semi-Quantitative Effectiveness of Field Kits

At a semi-quantitative level, the kits are moderately effective. That is, the kits can reasonably well place groundwater into a broad range.

Table 3: Semi-Quantitative Effectiveness of Field Kits

Range	# In range, by Arsenator	# In range, by field kit	% In range, by field kit
< 10	31	23	74%
10 - 49	15	10	67%
50 - 199	9	4	44%
> 200	3	2	67%

Further analysis of semi- quantitative effectiveness of field kits is given in Appendix 5.

6.2.3 Qualitative Effectiveness of Field Kits

The field kits are primarily needed to identify whether water tested contains above or below the government drinking water limit of 50 ppb. At this qualitative level, the field kits were found to be very effective. In about 85% of cases, the field kit correctly identified 'green' (< 50 ppb) and 'red' (>=50 ppb) tubewells (compared to Arsenator results). If a tolerance of 50% is extended then the kit is approximately 93% effective at identifying both 'red' and 'green' tubewells.

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Table 4: Qualitative Effectiveness of Field Kits

Range	# In range, by Arsenator	# In range, by field kit	% In range, by field kit	# In extended range*, by field kit	% In extended range*, by field kit
< 50 (Green)	46	39	85%	43	93%
>= 50 (Red)	12	10	83%	11	92%

* Extended range: for green, < 75 ppb; for red, > 25 ppb

6.3 Discussion

6.3.1 Quantitative Performance

Figure 2 shows that while there is a positive correlation between the concentrations reported by the field kits and the Arsenator, there is a very large amount of scatter. The scatter is somewhat mitigated by making a log-transformation, as shown in **Figure 3**, which shows a more clear trend between the two analytical methods. Both figures showed that the field kits, on average, reported higher arsenic levels than the Arsenator. This was unexpected, and could be explained in three ways:

1) The field kits could actually overestimate arsenic levels;
2) The Arsenator could actually underestimate arsenic levels; or
3) During sample storage, arsenic could have been removed from solution.

The second explanation is quite possible. The Arsenator has not been independently evaluated in laboratories as yet. An evaluation is underway, and should soon clarify this issue. Based on preliminary reports from the laboratories assessing the Arsenators, there is no major negative bias.

The third explanation is more plausible. The samples were stored for some two months before analysis. Although the samples were acidified, it is conceivable that arsenic either precipitated out of solution, became adsorbed onto some insoluble materials in the water, or became adsorbed onto the plastic walls of the bottle. Other researchers have reported that arsenic levels measured in the field were higher than levels from the same source, measured in the laboratory after preservation and storage. In order to evaluate this possibility, it is necessary to conduct a field comparison of Arsenator and field kit results. This type of exercise will, in fact, be part of the continuing evaluation of the Arsenator.

If both of these explanations are investigated and ruled out, it would seem likely that the field kits produced by NIPSOM are actually overestimating arsenic levels. This is surprising, but not inconceivable. In any case, the large amount of scatter makes the field kits unreliable for quantitative measurement, even if they can detect low levels. The field kits may well be sensitive, but not precise.

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6.3.2 Semi-Quantitative Performance

The field kits were fairly accurate in placing the analyzed water into a broad category of contamination. More tests would need to be made, especially for moderately and highly contaminated samples, to determine what kind of tolerance range would be required.

6.3.3 Qualitative Performance

This study found that the field kits did quite well at identifying green/red wells correctly. Table 3 showed that, with 50% tolerance, 93% of the analyses (both positive and negative) were correct.

Figure 3 shows that there were a certain number of false positives samples, where the field kit indicated more than 50 ppb, but the Arsenator showed from 10 - 50 ppb. These are of particular concern programatically, as they result in a 'safe' tubewell being painted red. However, from a public health perspective, false positives are much preferable to false negatives, only one of which was found in this study. It is conservative to accept a small number of false positives, especially since all of those noted in this study were above the WHO guideline value of 10 ppb.

It should, however, be noted that the sample size in this study was small.

7. Conclusions and recommendations

This study showed that rapid testing of high numbers of tubewells is possible with high quality and management. It can be concluded that the field staff were using the equipment correctly and consistently . The data also suggests that the NIPSOM field kits can perform adequately, for qualitative, or at best semi-quantitative measurement of arsenic.

The study also showed that DPHE have been relatively successful at avoiding arsenic affected areas, only 4% of tubewells tested were found to have arsenic above the accepted level and tubewell installations have been reduced as a result of these efforts.

The field testers found 484 inactive tubewells, a recommendation for future testing would be to include further investigation into reasons why tubewells are inactive. These issues were not addressed in this study.

The arsenic problem in Bangladesh is a threat to public health. Not only did this study strongly confirm the existence of the arsenic but is also provided valuable information on effectiveness and quality of field testing and location of hazardous tubewells,. The problem of Arsenic is a matter of grave concern particularly in certain areas. To mitigate the problem in Bangladesh, rapid detection of arsenic contaminated tubewells, provision of safe water, treatment of affected persons and health awareness in the community is