APSU
Arsenic Policy Support Unit

Risk Assessment of Arsenic Mitigation Options (RAAMO)

Final Report, September, 20005

ITN-Bangladesh

Risk Assessment of
Arsenic Mitigation Options (RAAMO)

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Published by:
APSU
14 Capt. Monsur Ali Shorani
Kakrail, Dhaka-1000, Bangladesh

September, 2005

ISBN 984-32-2675-5

The report was prepared for the Arsenic Policy Support Unit (APSU), Local Government Division, Ministry of Local Government, Rural Development and Cooperatives, Government of Bangladesh with financial support from the Department of International Development (DFID), UK. The views expressed in the report are solely the responsibility of the study team and do not necessarily reflect the views of the Government of Bangladesh, DFID and ITN-BUET

The Material in this report may used provided it is properly cited.
Citation should be:
Ahmed M F, Shamsuddin S A J, Mahmud S G, Rashid H, Deere D and Howard G, (2005) ‘Risk Assessment of Arsenic Mitigation Options (RAAMO)’ APSU, Dhaka

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Foreword

This report is the output of a risk assessment of arsenic mitigation options that was undertaken by ITN-BUET over a 12-month period with funding from the Arsenic Policy Support Unit (APSU). This study was meticulously designed and involved the inputs from a number of national and international experts. This study is the first of its kind in a developing country and will support balanced decision making by water and health professionals engaged in arsenic mitigation.

The purpose of the risk assessment was to quantify the health risks associated with different arsenic mitigation options. In providing alternative water supplies, it is important to be aware that users may be exposed to other hazards such as pathogens. Risk substitution in arsenic mitigation should always be avoided and water should be provided that is safe with respect to all contaminants. This will ensure that the targets set out in the Poverty Reduction Strategy Paper (PRSP) and the Millennium Development Goals will be reached.

This study has developed a tool to allow the estimation of disease burden associated with pathogens and arsenic for each technology. This has been validated using the data collected in this study, but it is important that the tool should continue to be used. All organisations wishing to have support to analyse their water supplies should feel free to use this tool and to contact either APSU or ITN-BUET for advice and support.

For sustainable arsenic mitigation, the technologies provided must be acceptable to the users. This study also included an assessment of social acceptability and this can be used to undertake an overall assessment of suitability using a triple-bottom line approach. Sustaining mitigation options also requires that support is given to communities so that they can undertake the routine operation and maintenance tasks required.

This risk assessment is part of a process to develop a water safety framework for Bangladesh. It provides support to defining health-based targets for water supply and in determining the major risks that must be addressed in a water safety plan. Water safety plans are already being implemented through water supply projects working with rural communities. The use of such plans linked to risk assessment will offer Bangladesh an effective system for ensuring safe drinking water is supplied to all rural communities.

Dr. Guy Howard
International Specialist
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Acknowledgement

The study team wishes to acknowledge the fact that the research undertaken for the Risk Assessment of Arsenic Mitigation Options (RAAMO) and the subsequent preparation of this report was a concerted team effort. A very meticulous design of the approach and methodology and deployment of respective professional inputs at strategic point of time during the study are important to recognise. In the quest of ensuring a high level scientific study, which is the first of its kind in the region, the research team included a number of national and international experts.

The team likes to mention here with gratitude the inputs from the professionals from ITN-BUET and its Associates. The Principal Investigator, technology specialist, social scientist and other related experts were mobilised from this resource pool in addition to inputs from a senior sector professional for the overall research management. It goes without saying that well coordinated field and laboratory activities were essential to ensure quality outcome of the study. This task of co-ordination was precisely maintained and the study team would like to thank its Field Co-ordinator for his sincere services. The services from the Environmental Division's laboratory of BUET and ICDDRB for water quality testing are acknowledged with appreciation.

The participation of Water Futures, Australia in the study team, particularly for the development of QHRA model and microbiological aspects, is gratefully acknowledged. Similarly, the study team would also like to thank Dr. Margaret Ince for her useful contribution with respect to survey design and setting water quality parameters during phase one of the study (RAAMO-I).

In order to get feed-back from all concerned sector professionals, APSU had arranged roundtable discussions on 24 June 2004 at an interim phase and arranged for peer review by key sector stakeholders of the draft of RAAMO-I report. After incorporation of the comments, observations and inputs, the RAAMO-I report was widely circulated by APSU during August 2004. Also the study findings were shared with all the concerned professionals in the National Conference on Water Quality and Surveillance, jointly organised by APSU and WHO, primarily to seek further comments, observations and inputs to enrich the report. Similarly, the RAAMO-II report was widely circulated in July 2005 for comments, observations and inputs. In addition, the material was regularly shared at forums like the LCG sub-group for water supply and sanitation. International peer review from Peter Teunis, RIVM, The Netherlands and Jamie Bartram from WHO Geneva is also gratefully acknowledged. The study team would like to take this opportunity to express its sincere appreciation to all those sector stakeholders and professionals for their valuable inputs and particularly to APSU for its arranging such feedback from all concerned stakeholders and professionals.

Finally the study team would like to thank APSU for its continued support and financial assistance without which it would not have been possible to undertake the research of such magnitude and dimension.

It is expected that this research outcome will fill up knowledge gaps in this particular area of the water supply sector and researchers, planners and others concerned will be benefited from this product.

Sk. Abu Jafar Shamsuddin, PEng.
on behalf of the
Study Team of RAAMO

EXECUTIVE SUMMARY

Background

Arsenic contamination of groundwater has rendered about 2 million shallow tubewells unsafe for drinking water supply and exposed up to 30 million people to arsenic exceeding Bangladesh Standard for arsenic. The National Policy for Arsenic Mitigation (2004) states that access to safe water for drinking and cooking shall be ensured through implementation of alternative water supply options in all arsenic affected areas. The Implementation Plan for Arsenic Mitigation in Bangladesh (2004) identified alternative technology options for arsenic-safe water supply, which include surface water treatment, improved dug well, rainwater harvesting, deep hand tubewells, arsenic removal technology and piped water supply.

Considering the urgency and gravity of the problem, alternative options of drinking water supply are being installed in arsenic affected areas under arsenic mitigation programs. However, in many cases alternative water sources are installed without taking into account the relative health risk posed by those options and possible risk substitution.

In this context, the Risk Assessment of Arsenic Mitigation Options (RAAMO) was launched to understand the relative health risk, risk management potential and social acceptability of the widely used technology options, which include deep tubewell (DTW), dug well (DW), pond sand filters (PSF) and rainwater harvesting system (RWHS). The study aimed, in particular, to quantify the potential health risk through quantitative health risk assessment (QHRA) and understand how the risk could most effectively be managed and water safety promoted in arsenic mitigation in Bangladesh.

Methodology

The study was composed of three sub-components.

1) A water quality and sanitary integrity study of a statistically representative sample of arsenic mitigation options spreaded across the country using a cluster sampling approach. The number of water sources selected for field study included 36 DWs and 36 DTWs from 12 randomly selected clusters of Upazilas and 42 PSFs and 42 RWHSs from 14 clusters of Upazilas.

   The contaminants likely to be present in water from DW, DTW, PSF and RWH were analyzed adopting standard methods. The presence of arsenic, thermotolerant coliforms (TTC), with confirmatory testing of *E.coli* on positive samples, and other selected physical and chemical water quality parameters were examined at each water points. The sanitary integrity of all water points was assessed using standard sanitary inspection format, based on examples from WHO Guidelines Volume 3 and those used in previous surveillance projects and adapted to suit Bangladesh conditions. In order to take into account the seasonal variations, the study was conducted in both dry and monsoon (wet) seasons.

2) A social acceptability study based on a questionnaire survey was conducted at each water point. The social survey was conducted on 178 households using DW, 180 households using DTW, 195 households using PSF and 61 households using RWHS as arsenic mitigation options.

3) A Quantitative Health Risk Assessment (QHRA) model was developed. The model used water consumption, life expectancy, age group distribution and a series of assumptions relevant to Bangladesh to estimate disease burden. The model used arsenic and TTC as input data to give an output as a disease burden expressed in terms of disability-adjusted life years (DALYs). The use of DALYs enables risks from different types of hazards and different types of diseases and sequelae to be compared in a common metric.

   The model used three reference pathogens as recommended in the 3rd edition of the WHO Guidelines for Drinking-Water Quality (WHO, 2004). Estimates of the likely presence of the reference pathogens were made based on the relationship of the pathogens to TTC in sewage based on long-term monitoring studies.

   Arsenic was also included in the model and the disease end-points incorporated include skin cancer, lung cancer and bladder cancer. The model was designed in an Excel spreadsheet to enable estimation of disease burden for particular water supplies and water supply technologies in particular locations. This simplifies the presentation of the health aspects of the water supplies.

Findings

Water quality

- Thermotolerant coliforms were detected in most DWs (94%) in high numbers and the level of contamination of DW water increased drastically in the monsoon season. More than 50% of the DWs showed a TTC count more than 500 cfu/100ml in the monsoon season as compared to 3% contaminated to that level in the dry season. Inflow of contaminated surface water in the rainy season may be the cause of such an increase in the level of contamination of DW water. The high level of bacterial contamination of dug well is consistent with previous studies.

- A few number of DTWs (8%) were found to be contaminated with TTC in the dry season, although this increased to 47% in the monsoon. Numbers of TTC in both seasons were very low. Contamination in deep hand tubewells probably results from unhygienic practices and use of contaminated priming water.

- About 95% PSFs water samples were found contaminated in both the seasons with higher level of TTC in the monsoon season compared to dry season. High level of contamination of pond water, inadequate filter depth and poor maintenance of PSF are the main reasons for high microbial contamination of PSF water.

- In case of RWHS, 43% of samples had TTC in the dry season and 63% in the monsoon season. Contamination was generally of low level and much lower than PSF and DW but higher than DTW. Contamination appears to occur from unclean roof catchments, insanitary surroundings and poor handling of water in RWHS practiced in Bangladesh.

- The level of microbial contamination of DW and PSF waters suggests that better sanitary protection and disinfection of waters from these sources are needed for safe operation as arsenic mitigation options. Disinfection is likely to be of particular importance in the monsoon season.

- Arsenic was present in DW water, 3% above BDS and 25% above WHO GV, confirming with other studies that DWs are not universally arsenic-safe. No arsenic was detected in the DTWs, although other studies have found 1 – 10% DTW contaminated with arsenic some areas. Arsenic was found at low levels in both PSF and RWHS waters. Arsenic in most water samples from RWHS and PSF was below detection level. A visible improvement in the chemical quality, particularly arsenic content of DW water was observed in the monsoon season. Dilution of the top layer of the aquifer by infiltration of rain and surface waters of low mineral content may be the cause of improvement of chemical quality of DW water.
- Iron and Manganese were present in both DW and DTW in excess of BDS and WHO GV. The concentration of nitrate in DTW, PSF and RWHS waters was within BDS while that in 8% of DW water exceeded BDS. Ammonia in excess of BDS was present in almost half of the DWs and DTWs and in over 70% of samples from both PSF and RWHS in the dry season and in 31% PSF and 18% RWH samples in the monsoon season. High pH values were observed in most of the water samples collected from RWHS probably due to leaching of calcium oxide from cement used for the construction of rainwater storage tank, which should improve with the curing of concrete. The pH levels of waters from DW, DTW and PSF were close to neutral.

Sanitary integrity

- Sanitary inspection shows that RWHS had the best sanitary protection with a median sanitary risk score in the 'low risk' category as compared to DW, DTW and PSF having scores in 'intermediate to high risk' category in both seasons. In spite of high sanitary risk, DTW produces water of best microbial quality because of greater protection of deep aquifer from contamination. Improved sanitary protection in all arsenic mitigation options is required to improve the microbial quality of water.

- A combined analysis of sanitary inspection and TTC data was undertaken to produce a combined risk grading for each technology. The combined risk grading of DW and PSF increased greatly in the monsoon, resulting in a great deterioration of microbial quality of water from these options in the monsoon season. The combined risk grading of RWHS, in contrast with other options, showed small improvement in the monsoon season.

- Among the risk factors lack of protection of water sources, insufficient width and cracked apron, water ponding and inadequate drainage and sources of pollution near water points contributed higher risks of contamination by creating a source of hazards and routes into the water sources. These factors deserve the highest attention in improving the sanitary protection of these water supply options.

- Analysis suggested that sanitary risk factors can be controlled through compliance with construction protocols, raising awareness within the community, behavioural changes within the community and ensuring community participation in planning, implementation, operation and maintenance. Disinfection of DW and PSF waters is required for full control of microbial contamination and this should be incorporated within water safety plans.

Social study

- The vast majority of the respondents provided with a DW, DTW and PSF considered the options as a permanent solution to arsenic problem. A lower proportion of users majority considered RWHS to be a permanent solution, although this was still a majority of users. Poor households were more likely to see community mitigation options as their only way of accessing arsenic-safe water for drinking and cooking. The respondents were generally satisfied with the quality of the water but greater satisfaction was expressed in favour of RWHS, PSF and DTW waters as compared to DW water.

- Most households used the mitigation option immediately after it was installed, and almost all within six months of the installation. Of households who did not start using the mitigation options immediately after installation, distance was mentioned as being the primary factor. The DW and PSF users also cited uncertainty about water the quality as being the reason for non-use of the mitigation option.

- The shift from red STW, distant green STW and other sources to newly installed arsenic mitigation options for drinking and cooking is satisfactory. However, some households used red STW and other sources for domestic propose other than dinking and a small percentage of household depending on the mitigation option occasionally used red STW water for drinking.

- In cases where user groups or community based organisations (CBOs) were reported to have been formed, only small percentage of the respondents knew of their presence. The assessment indicated that the process of user group or CBO formation was not very participatory and very few users actively participated in planning and implementation of the systems. No respondent, except those who had given land to install the facilities was found to be directly involved in decision making on the water point.

- The water points studied under RAAMO were new in terms of age and did not show major operation and maintenance problems but sanitary inspection data showed that O & M was already beginning to deteriorate in many supplies and this may prove to be a problem in the future. Future programmes need to commit more resources to develop local user-based mechanism for effective management and O & M of mitigation facilities.

- Majority of the respondents have heard of arsenic in the last two years. Of the total households interviewed using the arsenic mitigation options, just over half knew that arsenic is a poison that gradually affects health and just under half could identify at least one physical symptom of arsenicosis. Only about 3% of the respondents knew that arsenicosis was not contagious. A majority of respondents knew that water from tubewells marked red should not be used, but 78% of the respondents did not know that water from red tubewells may be used for purposes other than drinking and cooking.

- The high proportion of use of, and user satisfaction with, arsenic mitigation options proves beyond doubt the social acceptability of all the options. From the social perspective there is no problem in promoting these as mitigation options in arsenic affected areas.

- Future arsenic mitigation programmes that deliver community facilities must improve on building awareness giving emphasis on the use of water from red tubewells for purposes other than drinking and cooking; and that arsenicosis is not contagious. Awareness campaigns on arsenic and its ill affects should bear in mind that the best means of spreading messages are through radio and television, NGOs and word of mouth.

Health risk

- A quantitative health risk assessment (QHRA) model was developed and has shown to be very useful in terms of calculating the likely disease burden associated with water sources based on three reference pathogens and arsenic. The QHRA provides a valuable input to decision-making processes in relation to water supply mitigation options.

- The viral and bacterial pathogen concentrations dominated the disease burden estimates where the contribution by protozoal pathogen to the total microbial DALY was negligible. In case of arsenic, skin and lung cancers dominated the arsenic disease burden where lung cancer was the greater contributor to arsenic DALY than skin cancers across the range of values used for the study.

- The model shows that there is significant health risk substitution for DWs and PSFs with respect to pathogens. There is much lower risk substitution in DTWs and RWHSs in relation to either pathogens or other chemicals. Hence, DTW had the highest aggregate water safety followed by RWHS, while disease burdens from DW and PSFwere unacceptably high. Additional interventions as identified by water safety plans (WSPs) would be required to get drinking water of acceptable disease burden from DW and PSF.

- The disease burden increased in the wet season with the greater deterioration of microbial water quality of DW and PSF. Although some improvement of arsenic content of water of both DW and DTW options were observed in the wet season, its influence on total DALY was insignificant as compared to microbial DALY.

Concluding Remarks

- The QHRA is an useful tool in comparative evaluation of different water supply options, supporting decision-making process and programme implementation in terms of technology selection. This process should be continued and the tool developed should be used to evaluate disease burdens associated with a larger number of technologies and management of water supply system. A manual for the QHRA tool is being developed and training for key stakeholders in the use of QHRA should be considered to improve dissemination.

- Based the data collected in this study and data presented in other studies, it is clear that in overall terms DTW offer the best option with regard to public health risks and therefore, wherever feasible DTW should be considered as the first mitigation option of choice. The lack of information about DTW safe areas and management strategy currently restricts the use of DTWs. It is essential that progress is made on developing a groundwater mapping and management strategy.

- The health risks associated with DW and PSF are much higher than DTW and RWHS. Nonetheless, it is clear that DW and PSF will continue to be key options for arsenic mitigation in many areas of Bangladesh. However, the data from this and other studies show that significant improvements in design, construction, O&M along with major interventions identified by WSPs are required if these are to provide safe drinking water.

- RWHS offer low-risk options that can be located at the house-hold level. However, the difficulty in providing a year-round water supply and unaffordability of the poor, restrict the use of RWHS. There is a need to develop lower-cost designs whilst improving overall storage. The use of communal RWHS has to date been limited and mainly practiced at schools. The potential for developing communal RWHS further is an important area for ongoing study.

- Community participation appears to be relatively poor throughout the process of mitigation option selection, location and subsequent operation and maintenance. Greater effort is required to develop effective community-based processes that will support the sustainability of the options.

- The WSPs should be implemented for all arsenic mitigation options to ensure that safe drinking-water is supplied in the long-term. The use of WSPs would also support greater community participation because of its emphasis on working with communities to monitor and manage their water safety effectively.

1

INTRODUCTION

1.1 Background

Water supply in Bangladesh is primarily based on groundwater sources. In the context of a very high prevalence of diarrhoeal diseases in Bangladesh, the control of microbial quality of water received priority in drinking water supply. Groundwater is generally of excellent microbiological quality and in Bangladesh is available in adequate quantities in shallow aquifers. The development of low-cost hand tubewell based water supply for the rural population is primarily based on these aquifers.

The country achieved a remarkable success by providing 97% of the population with access to improved water supply. However, this success is being overshadowed by the presence of arsenic in excess of acceptable levels in the shallow aquifers. Groundwater based water supply programmes that provide “safe’ drinking water in order to control diseases like diarrhoea, dysentery, typhoid, cholera and hepatitis have exposed population to arsenic related health problems. It has been estimated that about 29 million people in Bangladesh are exposed to drinking water with arsenic exceeding Bangladesh Standards of 50 μg/L and 49 million exceeding provisional WHO Guideline value of 10 μg/L (GOB, 2002). Thus arsenic contamination has reduced the estimated national population coverage with safe water supply from 97 to 74% (Ahmed, 2002).

Blanket screening of shallow tubewells in 270 affected Upazilas has shown that 29% (or about 1.5 million tubewells) of about 5 million tubewells tested had arsenic concentrations exceeding the Bangladesh Standard of 50 μg/l (NAMIC, 2004). There are 8,540 villages in Bangladesh where more that 80% tubewells used as only source of drinking water are contaminated with arsenic. Total of 38,430 cases of arsenicosis have been identified under national screening programme. The provision of arsenic-safe water is urgently needed for the protection of health and well being of the rural population living in arsenic problem areas and to ensure that Bangladesh is able to meet the targets outlined in the Millennium Development Goals.

Considering the urgency and gravity of the problem, alternative options of drinking water supply are being installed in arsenic affected areas under arsenic mitigation programmes. However, in absence of scientific studies, the relative risk to health of these different options have not been given due consideration when designing the mitigation programme.

Risk substitution is a possible consequence of introducing options without adequate scientific evaluation in the present context of Bangladesh (Howard, 2003).

The main sources of water in Bangladesh are surface waters in rivers, reservoirs, lakes, canals and ponds; and groundwater in shallow and deep aquifers. In general, groundwater flows into surface water sources in the dry season and surface water recharges groundwater sources during the monsoon. The interrelated nature of these two sources therefore implies that the use of one source may have an impact on the water available from the other source. The surface and groundwaters available in Bangladesh are abundant but the quality of water of these sources has become the main constraint for the development of safe and affordable water supply systems. The surface water sources are becoming increasingly polluted from domestic and industrial wastewaters. The presence of arsenic in groundwater has now become the major water supply problem in Bangladesh.

Another source of water in Bangladesh is rainwater, which is available in adequate quantity in the monsoon. The average yearly rainfall in Bangladesh is around 2450 mm, which is a source of water for the replenishment of both surface and groundwater sources. The collection of rainwater for domestic use is a further potential source of water for arsenic mitigation.

The National Policy for Arsenic Mitigation (GOB, 2004) states that access to safe water for drinking and cooking shall be ensured through implementation of alternative water supply options in all arsenic affected areas. The Policy recognises that technology options are area dependent and that no single option can serve the purpose of a population having a diverse socio-economic background. Therefore, arsenic mitigation programmes must promote a range of technology options for water supply that have been approved for arsenic affected areas by the National Committee of Experts and the Secretaries Committee on Arsenic. The policy states that preference should be given to surface water over groundwater as source of water supply and mitigation programmes should endeavour to promote piped water systems wherever feasible (GOB 2004). Piped water schemes must ensure that the poorest members of the community have access to safe water that meets the minimum service levels established by the Government.

While the search to devise appropriate water supply is underway, the Implementation Plan for Arsenic Mitigation in Bangladesh (GOB, 2004) promotes a number of alternative technological options for arsenic-safe water supply. These include improved dug well, surface water treatment, deep hand tubewells, rainwater harvesting, arsenic removal technology and piped water supply systems. Priority has been given on the use of surface water and improved dug wells in the implementation plan for arsenic mitigation, although an inter-Ministerial committee will be convened by the Local Government Division to determine where deep hand tubewells can be deployed. The preference for dug wells and surface water is a major shift in respect of selecting a source for drinking water supply, which has been justified in the context of elevated levels of arsenic in the groundwater and complexities involved in its treatment.

Surface water of relatively good quality can be made potable by low-cost treatment but little is known about the quality of treated water at the present level of contamination of surface water sources. Furthermore, results from organisations using surface water treatment and dug well show that proper control over microbial quality of these water supply options in the rural context can be a difficult task.

In meeting the needs of the National Policy for Arsenic Mitigation and Implementation Plan for Arsenic Mitigation in Bangladesh there is a requirement to evaluate available water supply options as a means of defining appropriate technical mitigation responses. Mitigation options should provide water that is arsenic safe whilst controlling other potential health risks at a level that is tolerable. In the resource constrained situation of Bangladesh, the potentials of alternative options to meet the present and future needs of the population requires critical evaluation. It is necessary, therefore, to have a clear understanding of the risks associated with different options and to provide a quantitative estimate of the likely health burden arising from these risks. Further, it is necessary to establish how these risks may be managed.

This report presents the findings of the study on Risk Assessment of Arsenic Mitigation Options (RAAMO). The aim of this study was to quantify potential health risks from the use of alternative water sources and identify ways in which risks may be effectively managed. Considering the magnitude of field-work involved, the risk assessment study was designed to be completed in two phases. Phase 1 of the study covers the quantitative health risk assessment (QHRA) of dug wells (DWs) and deep hand tubewells (DTWs) and their performance in the dry season. Phase II covers the QHRA of DWs and DTWs in the monsoon season and pond sand filters (PSFs) and rainwater harvesting (RWH) in the monsoon and dry seasons. Arsenic removal technology and piped water supply systems have been excluded from this study as both the systems are still in development stage and few systems have been deployed in the country.

This report forms part of a series of reviews and studies supported by the Arsenic Policy Support Unit to provide the sector with information to support implementation of safe drinking water supplies and arsenic mitigation. The report is aimed at policy makers and programme managers to help them in decision-making, planning and delivery of arsenic mitigation programmes.

1.2 Objectives of the Study

The principal objective of this study is to make a quantitative health risk assessment (QHRA) of the four alternative water supply options identified in the implementation plan for arsenic mitigation in Bangladesh. Risk assessment is a tool used internationally to set drinking water quality standards, make comparison of drinking water sources and develop water safety plans.

In undertaking a QHRA, it is important to address the potential health impacts of potential hazards that may be associated with water quality and the acceptability of the water by the end-users. Quantitative health risk assessment (QHRA) needs the understanding of the intensity and magnitude of bacteriological and chemical contamination of health concern and health outcomes from infection with particular pathogens and exposure to toxic chemicals. Exposure to chemicals or pathogens can result in a number of outcomes, typically ranging from non-symptomatic infection, through mild self-limiting diseases to severe morbidity outcomes and mortality. Secondary outcomes, where these occur, must also be taken into account within the overall estimate of the burden of diseases.

The components of this QHRA study of arsenic mitigation options include:

a. Assessment of water quality and sanitary integrity;
b. Assessment of social awareness and acceptability; and
c. The development of a model for the assessment of health risk.

The assessment of water quality and sanitary integrity is intended to:

- understand the magnitude of water quality problems associated with different alternative water supply options for arsenic mitigation;
- assess the risk of contamination through sanitary inspection of the options in operation; and
- identify how sanitary risks may be controlled to reduce the risk of microbial contamination.

The objectives of social studies are to:

- assess the users' acceptability of the technologies;
- understand the perception of users about water quality and health issues and adoption of alternative options to reduce risk; and
- Assess the level of operation, repair and maintenance, and functioning of the water points.

The final component of the study is to develop a model for the assessment of health risk associated with arsenic mitigation options with the following objectives:

- estimate the risk to health from different hazards related to the quality of water produced by an arsenic mitigation option and total health outcomes in terms of disability adjusted life years (DALYs);
- development of water quality health index that can be applied to assess the performance of different technologies; and
- preparatory work on effective risk management through the use of water safety plans (WSP).

The main problem of QHRA studies in developing countries is the lack of data on which to base the estimates of disease impacts. The first and second components of this study are designed to compile health and social data for the estimation and management of health risk.

The different components of the study meet different specific needs within arsenic mitigation. The water quality and sanitary integrity study provides an indication of current performance and through the use of information from sanitary inspection can be used to define better design, construction, and operation and maintenance. The sanitary inspection data can also inform the requirement of training programmes for communities, in particular in relation to monitoring and managing the safety of their drinking water. This data therefore helps in direct project or programme planning.

The social acceptability study provides useful information regarding the extent to which options are acceptable to users, the degree of participation of users in decision-making and the knowledge and awareness of key issues related to water supply management and arsenic. The data provide useful inputs to programme and project management, as well as informing policy and national strategy refinement needs.

The QHRA model provides an indication at a national level of the likely disease burden that may be introduced through switching to a different source of water. It therefore informs policy and national strategy and can form the basis for establishing health-based targets for water supply that reflect the socio-economic conditions in Bangladesh and national goals for public health protection. The model and its outputs are not meant to act as a programme planning tool for implementing water supply projects in individual communities. The latter will be based on the development of generic water safety plans.

1.3 Organization of the Report

The Risk Assessment of Alternative Arsenic Mitigation Options (RAAMO) report has been organized in seven sections with an introduction to the problem and objectives of this study in section 1. Section 2 provides a description of the alternative water supply technologies included in this study; dug well, deep hand tubewell, pond sand filters and rainwater harvesting (RWH). The methodologies used in the fieldwork component of the study have been described in section 3. Section 4 presents the results of the water quality and sanitary integrity assessment. Section 5 presents the findings from the social study. The quantitative health risk model and use of the model for QHRA of the alternative water supply options under the study are described in section 6. The findings and conclusions of the study are summarised in section 7, while sources of information and related additional data of the study are included in the references and appendices respectively.

2

ALTERNATIVE WATER SUPPLY TECHNOLOGIES

2.1 Introduction

The alternative water supply options included in this study are dug wells (DWs), deep hand tubewells (DTWs), pond sand filters (PSF) and rainwater harvesting systems(RWHSs). An updated progress with provision of arsenic mitigation options to the end of December, 2004 shows that about 71,284 DTWs; 5,626 DWs; 13,716 RWHSs; 3,396 PSFs; 3,771 AIRUs (arsenic and iron removal units) and 39 piped water supply systems have been implemented by different organizations under arsenic mitigation programmes (APSU, 2005).

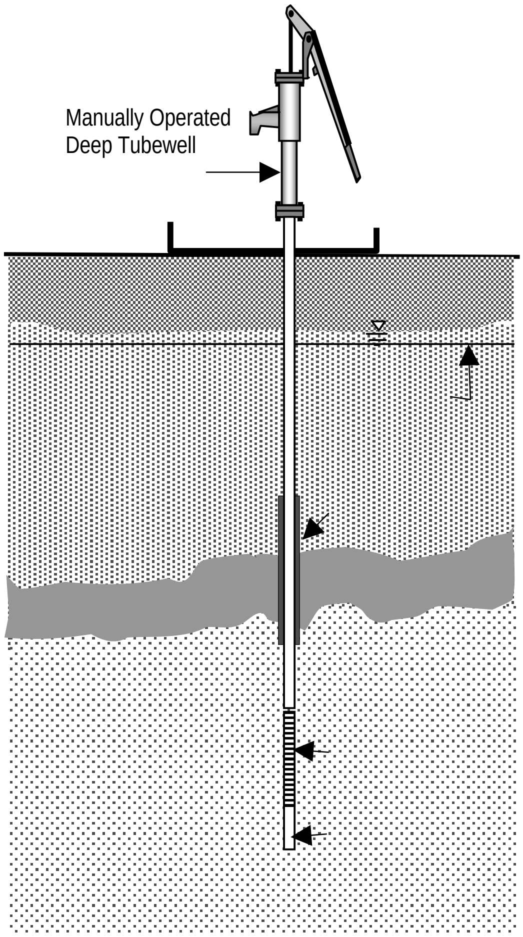
The major alternative water supplies deployed under arsenic mitigation programmes are DTWs, RWHSs, DWs and PSFs. The risk assessment of these major alternative water supply options has, therefore, been included in this study. Guidelines and protocols for installation of DWs, DTWs and PSFs have been developed under the Implementation Plan for Arsenic Mitigation in Bangladesh (GOB, 2004). This section describes these major alternative water supply options in relation to their deployment, suitability, advantages and disadvantages in the context of rural Bangladesh.

2.2 Deep Tubewell (DTW)

The Pleistocene aquifers in Bangladesh that are typically found at deeper levels have been found to be relatively free from arsenic contamination (Islam and Uddin, 2002). The use of groundwater and role of deep hand tubewell for arsenic-safe water supply have been described in detail by Ahmed (2003). The aquifers in Bangladesh are stratified and in most places the deeper aquifers are separated from contaminated shallow aquifers by relatively impermeable strata (aquicludes or aquitards). In a system of stratified aquifers, a tubewell that collects water from a deeper aquifer leaving one or more water bearing aquifers above is called a deep tubewell.

In Bangladesh two types of deep tubewells are installed, manually operated small diameter tubewells similar to shallow tubewells (see Figure 2.1) and large diameter power driven deep tubewells called production wells. DTWs installed in those protected deeper aquifers (where an aquiclude exists) are producing arsenic safe water. BGS and DPHE (2001) showed that only about 1% deep tubewells having depth greater than 150 m were contaminated with arsenic higher than 50μg/L and 5% deep tubewells had arsenic content above 10μg/L.

There are some areas where separating impermeable layers are absent and aquifers are formed by stratified layers of silt and medium sand. The deep tubewells in those areas may yield arsenic safe water initially but are likely to show increased arsenic content of water with time due to mixing of contaminated and uncontaminated waters. The possibility of contamination of the deep aquifer by inter-layer movement of a large quantity of groundwater also cannot be ignored. If the deep aquifer is mainly recharged by vertical percolation of contaminated water from the shallow aquifer, the deep aquifer is likely to become contaminated with arsenic. For instance, in some places in Jessore and Sylhet where there is no clear stratification of aquifer layers, many of the deep tubewells are arsenic contaminated.



Where the recharge of the deep aquifer is by infiltration through coarse media and replenishment by horizontal movement of water, the deep aquifer is likely to remain arsenic free even after prolonged water abstraction. The identification of areas having suitable deep aquifers and a clear understanding about the mechanism of recharge of these aquifers are needed to develop DTW based water supply systems in Bangladesh.

In most coastal areas, DTWs have been producing low salinity, arsenic safe water for a long time. The Department of Public Health Engineering (DPHE) has sunk a total of 81,384 deep tubewells mainly in the coastal area to provide safe water to 8.2 million people (DPHE, 2000). DTWs, as recommended in the Implementation Plan for Arsenic Mitigation in Bangladesh, can be installed in these coastal areas of Bangladesh having proven safe aquifer (GOB, 2004). In the other arsenic affected areas of Bangladesh, the presence of protected deep aquifers is not well recorded. Installation of deep hand tubewells in these areas will require that implementing agencies follow the protocol for installation of arsenic safe tubewells in arsenic affected delta and flood plain areas of Bangladesh (GOB, 2004).

Sealing of the annular space around the tubewell has been emphasised in the protocol for installation of deep hand tubewells to protect the deeper aquifers from contamination (Figure 2.1). In soft unconsolidated clay, the boreholes are automatically sealed by overburden pressure of soil. The deep tubewells installed under GOB V program are being sealed by inserting mud balls prepared by a mixture of clay and bentonite into bore holes.

Asia Arsenic Network used cement to seal the deep tubewells installed in arsenic affected areas. Proper sealing of boreholes at the level of impervious layer is a technological challenge. A standard practice in sealing the borehole at the level of impermeable layer is yet to be developed.

In general, permeability, specific storage capacity and specific yield of the aquifers usually increase with depth because of the increase in the size of aquifer materials. Experience in the design and installation of tubewells shows that reddish sand produces best quality water in respect of dissolved iron and arsenic. The reddish colour of sand is produced by oxidation of iron on sand grains to the ferric form. It will not release arsenic or iron in groundwater, rather ferric iron coated sand adsorbs arsenic from groundwater. For instance the Dhaka water supply is probably protected by its red coloured soil. Hence, installation of tubewell in reddish sand, if available, should be safe from arsenic contamination.

2.3 Dug Well (DW)

Dug wells (DWs) are the oldest method of groundwater withdrawal for water supplies in Bangladesh. The water from dug well is believed to have low dissolved arsenic and iron even in locations where tubewells are contaminated. The mechanism of producing water of low arsenic and other dissolved minerals concentration by DWs are not fully known. The following explanations may be attributed to the low arsenic content of dug well water (Ahmed, 2002):

- the oxidation of DW water due to its exposure to air in the well and agitation during water withdrawal may cause precipitation of dissolved arsenic and iron. The effect of covering the top of the well on this process remains uncertain but AAN (2003) found that increasing the time of exposure to air in the well had no effect on arsenic concentrations;
- DWs accumulate groundwater from top layer of a water table, which is replenished each year by arsenic safe rain and surface waters by percolation through aerated zone of the soil. The fresh water recharging the aquifer also has diluting effects on contaminated groundwater; and
- the presence of air and aerated water in well can oxidize the soils around DWs and infiltration of water into wells through this oxidized soil can reduce the concentration of arsenic in well water.

DWs are widely used in many countries of the world for domestic water supply. The flow into a DW well is actuated by lowering of water table in the well due to withdrawal of water. It can be difficult to protect the water of the DW from bacterial contamination. Percolation of contaminated surface water is the most common route of pollution of DW water, particularly where entry is possible in the upper parts of the lining or through open wellheads. The upper part of the well lining and the space between the wall and soil require proper sealing. The construction of an apron around the well can prevent seepage of contaminated used water into the well.

Water in a DW is very easily contaminated if the well is open and the water is drawn using bucket and rope (Figure 2.2). Satisfactory protection against bacteriological contamination is possible by sealing the well top with a watertight concrete slab. Water may be withdrawn by installing a handpump (Figure 2.3). In a completely closed DW, the inflow of water is actuated by suction created by the withdrawal of water from the well. If aeration is used to control the process of reducing arsenic contamination, the potential for reduced sanitary protection against microbial contamination may affect the quality of well water. Recently, improved DWs are constructed with improved sanitary protection but retaining an open wellhead to allow for aeration (Figure 2.4).

Figure 2.2: Water collection from an open dug well

Figure 2.3: Water collection from a closed dug/ring well by handpump

Figure 2.4: Improved dug well with opening for entry of light and air

Other than the rope and bucket system, different types of pumps are used to draw water from the covered DWs (Majed, 2005), which include:

a. DWs with tubewell or hand pump
b. DWs with Row pump
c. DWs with Tara pump
d. DWs with motorised pump

DWs with suction mode hand pump is shown in Figure 2.4. The suction mode handpump of No.6 tubewell is the common pump used for lifting water from the DW. It can be installed outside the DW for higher stability and is suitable for improved dug wells, which do not have a concrete slab for installation of pump directly on the well. A DW with a Row pump is shown in Figure 2.5. A Row pump is a suction pump and produces water continuously from a pump which is a rotating wheel attached to a handle as shown in Figure 2.5. The rotating wheel pulls a rope connected to circular pistons that move upward through a

pipe. The water is pushed upward through the pipe by piston and discharged through a spout for collection by users. A Row pump has to be installed directly on the well.

The Tara pump is a force mode pump used to raise water when the water level falls below the suction limit of about 24 ft, a particular in the dry season. The piston is set below the water level and the water is pulled up by direct action for release through the spout. A dug well with a Tatra pump is shown in Figure 2.6. The direct action Tara pump cannot be installed outside the well, hence a strong concrete slab is required on the well for erection of this pump.

Motorized pumps have been used in Bangladesh to raise water from community dug well to overhead water tanks for piped water supply.

Dug wells have not proved successful in many areas of Bangladesh that have a thick impermeable surface layer. In areas with thick clayey soil, DWs do not produce enough water to meet the volume requirements for users. In areas having very low water table and areas with loose sand and silt, there may be difficulty in construction of the well as well as withdrawal of water. Although tubewells in Bangladesh have replaced traditional DWs in most places, about 1.3 million people in both urban and rural areas are still dependent on DW for drinking water supply in Bangladesh (GOB, 2002).

2.4 Pond Sand Filter (PSF)

The National Policy for Arsenic Mitigation (GOB, 2004) has given priority on the use of surface water for arsenic-safe water supply. A prospective alternative water supply technology for the use of surface water is the construction of community type Slow Sand Filters (SSFs) commonly known as Pond Sand Filters (PSFs) in Bangladesh as it was originally designed for the treatment of low-saline pond water in the coastal area. The water from the pond/river is pumped by a manually operated hand tubewell to feed the filter bed, which is raised from the ground, and the treated water is collected through tap(s) as shown in Fig 2.7.

The operation conditions of slow sand filter include:

- Low influent turbidity, not exceeding 30 NTU;
- Low bacterial count, not exceeding 500/100ml;
- No algal blooms and absence of toxic cynobacteria; and
- Free from bad smell and colour

A protected surface water source is ideal for slow sand filtration. The problems encountered for not maintaining the above operation conditions are low discharge, need for frequent washing and poor effluent quality. Since these are small units, community involvement in operation and maintenance is absolutely essential to keep the system operational.

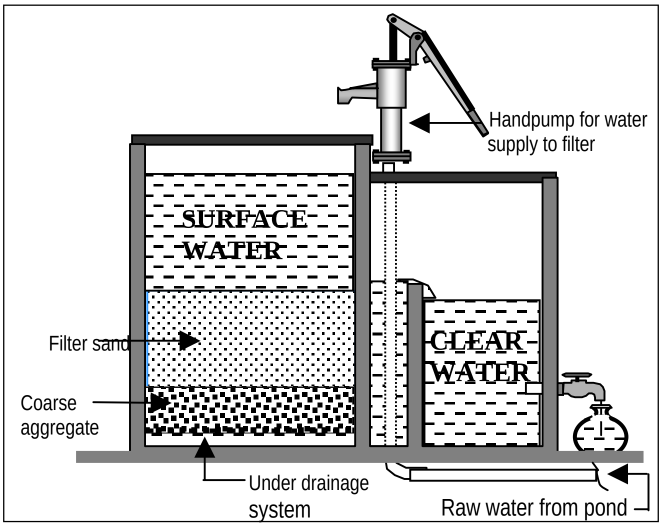


Figure 2.7 PSF for treatment of surface water

PSF is a community option and is designed to supply potable water for up to 50 families. They are constructed by the side of a pond, which contains adequate quantity of water throughout the year. Since the filter is a slow sand filter suspended matters including the micro-organisms are removed at the top of the sand bed. The treated water is then collected in a clear water chamber from where people collect water through taps (Figure 2.7). When operating conditions are met a properly designed filter can produce reasonably safe water in terms of bacteriological and physical quality. The factors that affect the filter performance include pond water quality, scraping of top sand layer, washing or replacing of sand and maintaining water head on the filter bed. The average length of filter run is about two months but primarily depends on suspended solid loads of the raw water. After this time the top layer of the filter bed needs scraping or replacement of sand. A photograph of a circular type PSF is shown in Figure 2.8.

Figure 2.8: A pond sand filter

Filter performance depends largely on the quality of raw water. In Bangladesh, the turbidity of pond water remains very high particularly during monsoon. When turbidity is above 30 NTU, the PSF does not work properly resulting quick clogging in the bed. Quick clogging of the filter bed eventually increases the burden of O&M of the system and also affects the quality of water produced. In order to increase the length of the filter run, some modified designs of PSF have been developed with an introduction of roughing filter with various up and down flow configurations. Roughing filters are made up of pea gravels placed in chambers arranged in descending order of gravel size (e.g. 15mm, 10mm, 5mm).

Roughing filters can reduce the load on the final sand bed to a great extent and thus increase the period between cleanings, and improve effluent water quality.

One of the main problems associated with the construction of PSF is the availability of ponds that are reserved only for PSF. Fish culture in pond is popular in rural Bangladesh as it generates direct income. Therefore people are reluctant to offer their pond to be used for PSF instead of fish culture. A pond that feed a pond sand filter is shown in Figure 2.9.

The other related problem is ensuring an adequate size of pond that can retain a sufficient quantity of water through out the year and prevent drying up during dry season. For ponds that need higher capacity to supply water round the year, it is recommended that the users' committee re-excavate the pond to increase its storage capacity. Re-excavation also helps by removing decomposable sludge from the bottom of the pond. Where ponds dry up during dry season groundwater can be supplied to the pond through irrigation wells. Even if the groundwater contains arsenic beyond permissible limit, the arsenic content gradually decreases through the process of aeration and sedimentation (AAN, 2004). However, frequent arsenic tests should be done to make sure that effluent water from the PSF does not contain arsenic beyond standard value.

Figure 2.9: Picture of a pond which feeds PSF

The PSF demands proper attention and careful maintenance of the system. Improper operation and maintenance leads to a quick deterioration of effluent water quality particularly microbial quality of water. Although PSF is efficient in removing microbial contamination, it may not attain 100% efficiency in case of highly contaminated raw waters and thus it is recommended to disinfect the treated water by chlorine before use. Different PSF models have been developed and implemented in the field by different agencies. The common designs in rural water supplies are known as DPHE-Unicef model, ITN model, DPHE-Danida model and the NGO Forum model.

2.5 Rainwater Harvesting System (RWHS)

Rainwater, available in adequate quantity in Bangladesh, is an alternative source of water supply in Bangladesh. Relatively high rainfall occurs in the Eastern part of the country and highest rainfalls greater than 3000 mm per year occur in North-eastern region and Eastern part of the coastal area. Lower rainfall, less than 1500 mm per year, occurs in the Western part of Bangladesh. The average annual rainfall in the coastal and hilly region is more than 3000 mm, against an average rainfall of about 2400 mm in Bangladesh. In these areas other suitable water sources are scarce because the coastal belt suffers from high salinity in surface and shallow groundwater, and the hilly areas suffer from an absence of surface and groundwater sources for the development of dependable water supply systems. RWH has been practiced for a long time on a limited scale in those areas. The seasonal high rainfall all over Bangladesh makes RWHS a potential alternative source of arsenic safe water. Rainwater collected from CI sheet roofs, or large plastic sheet can be safely stored in containers. The set up of a RWH system is relatively simple.

A rainwater based water supply system requires determination of the capacity of storage tank and catchment area for rainwater collection in relation to water requirements, rainfall intensity and distribution. The availability of rainwater is limited by the rainfall intensity and availability of suitable catchment area. The unequal distribution of rainwater over the year in Bangladesh requires a relatively large storage tank for uninterrupted water supply throughout the year, which constitutes the main cost of the system.

The catchment area for rainwater collection is usually the roof, which is connected with a gutter system to lead rainwater to the storage tank as shown in Figure 2.10. Rainwater can be collected from any types of roof but concrete, tiles and metal roofs give cleanest water. The C.I. sheet roofs commonly used in Bangladesh perform well as catchment areas.

The poor tend to be less able to utilise rainwater as a source of water supply. Poor people tend to have smaller thatched roofs to be used as catchment for rainwater collection. A thatched roof can be used as catchment area by covering it with polyethylene but it requires skill to guide water to the storage tank. In coastal areas of Bangladesh, cloths fixed at four corners with a pitcher underneath is used during rainfall for rainwater collection. Plastic sheets as shown in Figure 2.11 have been tried as a catchment for RWH for the people who do not have a roof suitable for rainwater collection.

The use of land surface as catchment area and underground gravel/sand packed reservoir as storage tank can be an alternative system of rainwater collection and storage. In this case, the water has to be channeled towards the reservoir and allowed to pass through a sand bed before entering into underground reservoirs. This process is analogous to recharge of underground aquifer by rainwater during rainy season for utilization in the dry season.

The quality of rainwater is relatively good but it is not free from all impurities. The rainwater is safe in terms of pollution by pathogens, but its quality may deteriorate during the process of harvesting. Analysis of stored rainwater has shown some bacteriological contamination; debris, wind blown dirt and bird droppings can contaminate the water collected. There the condition of the roof and storage tank is critical in maintaining the quality of rainwater. The first run off from the roof should be discarded to prevent entry of impurities from the roof. If the storage tank is clean, bacteria or parasites carried with the flowing rainwater will tend to die off. Some devices and good practices have been designed to store or divert the first foul flush away from the storage tank. In case of difficulties in the rejection of first flow, cleaning of the roof and gutter at the beginning of the rainy season and their regular maintenance are very important to ensure good quality of rainwater. The storage tank requires cleaning and disinfection when the tank is empty and at least once in a year.

Rainwater is essentially lacking in minerals and some minerals like calcium, magnesium, iron and fluoride are considered essential for human body in appropriate proportions. However, it is not clear what impact this low mineral content has on health, as the majority of such nutrients would be derived from food. The mineral salts in natural ground and surface waters sometimes impart pleasing taste to water. The lack of mineral content may affect the acceptability of the water. In a study carried out by BAMWSP during 2002, it was found that 34% of the respondent did not drink rainwater for its lack of taste ( )

Another risk associated with long storage of rainwater is the growth of algae and breeding of dengue mosquito inside the storage tank. When nutrients are present in the water algae grows in the tank quickly with the help of sunlight. Therefore, in addition to regular maintenance of the RWH system, the tank should be kept closed and wire mesh should be provided in the inlet and outlet pipe that runs in and away from storage tank.

The RWHs is comparatively good and easy to maintain. It is less vulnerable to contamination and quite easy to maintain its water quality if users pay a little attention and maintains the system properly.

3

METHODOLOGY

This section provides a description of the methodology used in the selection of arsenic mitigation options for the field survey to assess water quality and sanitary integrity and to assess social acceptability.

3.1 Selection of study communities

The field survey was based on a statistically representative sample of sources of each option type defined using cluster surveying across the arsenic affected Upazilas of Bangladesh.

3.1.1 Survey design

The method for selecting sites and water points for water quality assessment and sanitary inspection was derived from that developed for rapid assessment of drinking water quality within the WHO-UNICEF Joint Monitoring Programme (Howard *et al.*, 2003a). The survey methodology uses cluster sampling that has been peer-reviewed and is being used internationally. A summary of the process in survey design is given in Figure 3.1. The description of the steps with assumptions and relevant computation is given in detail in sections 3.1.2 to 3.1.6. All the assumptions are made considering the practical situation in rural Bangladesh.

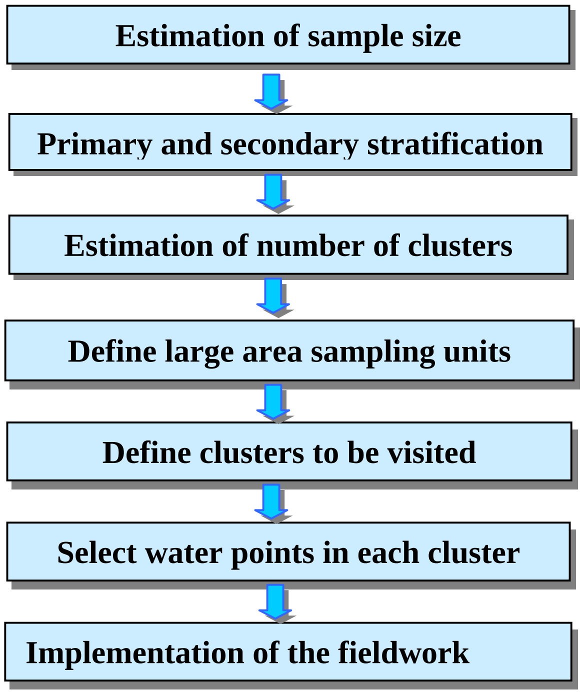


Figure 3.1: Survey design process for selection of water points

3.1.2 Sample size

The number of water points (n) to be sampled was determined using the following equation:

$$n = \frac{4 \cdot P(1-P) \cdot D}{e^2} \quad \ldots \quad \ldots \quad \ldots \quad (3.1)$$

The definition and the numerical value assigned to each parameter of Equation 3.1 with reasons are given in Table 3.1.

Table 3.1: Parameters for determination of sample size.

Parameter	**Definition**	**Agreed values for RAAMO study**	**Reason(s)**
P	Proportion of water points with a water quality exceeding bacteriological standard at some time	Figures calculated based on likelihood of contamination and proportion of population served (see equations 3.3 and 3.4 below)	Evidence shows that DW and PSF are prone to microbial pollution. DTW and RWHS have low microbial pollution risk and the sources of contamination are secondary.
D	Design effect (to take into account non-random effect of clustering)	2	Value most commonly used in Multiple Indicator Cluster Surveys (MICS) and there was no evidence to suggest greater non-randomness in relation to geographical area
e	Precision as a proportion	0.1	Gives 90% precision

In applying the equations, the sample sizes are determined based on the microbial quality of the water, as this is the parameter most likely to exceed the guideline value and pathogens would be the principal hazard that would substitute for arsenic. Overall poor microbial quality would provide the greatest health risk from water supplies.

The study was conducted in two different phases. In the first phase, DTWs and DWs were studied and in second phase PSFs and RWHSs were studied. In each phase two types of technologies having different proportions of contaminated points were surveyed. The proportion of contaminated point P for a technology can be calculated from the equation:

$$P = P_1 P_2 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3.2)$$

Where P_1 is the proportion of the technology among other technologies deployed in the area under study and P_2 is the proportion of that technology known to supply water exceeding the water quality standards.

In phase 1, DTW and DW were studied where the proportion of DTW deployed in the DTW areas (coastal area) is very high and the level of microbial contamination is very low. In case of DTW, P_1 and P_2 are assumed to be 0.9 (90% deployment) and 0.05 (5%) contamination. On the other hand DW serve very few people and the level of microbial contamination is expected to be high. Therefore, P_1 and P_2 for DW are assumed to be 6% and 90% respectively. If DTW and DW are taken together, the proportion of total water points exceeding water quality standard:

$$P = (0.90 \times 0.05) + (0.06 \times 0.90) = 0.099 \approx 0.10 \quad \ldots \quad (3.3)$$

Using the values P from Equation (3.1) and D and e from Table 3.1, the number of sources to be included was calculated as being:

$$n = \frac{4 \times 0.10\,(1 - 0.10\,) \times 2}{(0.1)^2}$$

$$= 72$$

Therefore, a total of 72 water points from DTWs and DWs were identified as being required.

The study on RWHS and PSF were conducted in phase-2 of the study. RWHs cover 5% (actually less than this) of the population and 50% of the RWH units are contaminated. PSF covers 10% (actually less than this) of the population and more than 90% of them are contaminated. So inserting these values in Equation 3.2:

$$P = (0.05 \times 0.5) + (0.9 \times 0.1) = 0.115 \approx 0.12 \ldots \quad \ldots \quad (3.4)$$

Putting the value of P from Equation 3.4 and value of D and e from Table 3.1 in Equation 3.1:

$$n = \frac{4 \times 0.12\,(\,1 - 0.12\,) \times 2}{(0.1)^2}$$

$$= 84$$

Therefore, a total of 84 water points from RWHSs and PSFs were identified as being required.

3.1.3 Primary and secondary stratification

It was agreed that primary stratification would be based on technology type. In this study the aim is to assess water quality and risk to health associated with different technologies used to mitigate against the presence of arsenic in the water delivered at the water point rather than to determine the actual populations at risk from each technology. Consequently, after calculating the total number of samples to be surveyed, an equal number of water points of each technology were included in phase 1 (i.e. 36 DTWs and 36 DWS) for convenience in stratification, clustering and collection of samples. Likewise, in phase 2, it was decided to spilt the number of water sources evenly between the two technologies and thus 42 RHW and PSF were included.

No secondary stratification for selection of clusters was applied because this was already largely addressed through the stratification by technology type, as DTWs and PSFs are mainly used in the coastal area and DWs and RWHS are used in other arsenic affected areas of Bangladesh.

3.1.4 Estimation of number of clusters

The number of water points that could be visited and sampled in one week was the primary consideration in estimating the number of clusters to be defined. It was assumed that in this study, all water points (DWs, DTWs, RWHS and PSF) would take the same time for sampling. A weekly sampling size of 12 water points was thought to be feasible. This was determined using a field programme with sampling on 3 days per week, 1-2 days per week for travel and 1-2 days per week for preparation, data entry and laboratory coordination.

The number of clusters determined was 72/12 = 6 for both DWs and DTWs and 84/12 = 7 for both RWHSs and PSFs. However, on exercising professional judgement to ensure representivity of the Upazilas, it was agreed to select each cluster containing 6 water points of each technology from different Upazilas. However, if 6 water points of two different technologies are available in one Upazila, both the technologies were sampled to avoid inter-Upazila travel and to save time. In addition during phase 1, 24 SHTWs (2 per cluster) were sampled for comparative purposes.

3.1.5 Large area sampling units definition

Information from various stakeholders indicated that interventions for arsenic mitigation are based around Upazilas, with different agencies generally working in mutually exclusive areas. It was decided therefore that the large sampling area would be the Upazilas.

3.1.6 Defining clusters to be visited

Six organizations under arsenic mitigation programme have started tubewell screening and mitigation activities in 268 Upazilas. According to the progress made so far it is observed that 1524 dug wells and 4434 tubewells have been installed by these six organizations. The DTWs constructed by DPHE under its regular GOB-IV programme were excluded but the PSFs constructed under this program were taken into account for this study. Considering the small number of PSFs constructed by other organizations, inclusion of the units constructed under GOB-IV was needed for better representation of this technology. The units installed by seven organizations are given in Table 3.2.

Table 3.2: The partner organisation in arsenic mitigation

Partner Organisation	No. 0f Upazilas	No. of DW	No. of DTW	No. of PSF	No. of RWHS
1. Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP)	188	497	537	12	0
2. DPHE-Unicef	25	617	0	67	2509
3. DPHE-Danida*	11	0	3645	11	97
4. DPHE-GOB-IV	16	-	**	355	-
5. World Vision	16	27	252	-	-
6. WatSan Partnership Project	15	332	0	-	-
7. Asia Arsenic Network	6	51	0	13	-
Total	-	1524	4434	548	2606

* Only those specifically constructed for arsenic mitigation were considered . ** The units constructed under GOB-4 were excluded

It should be noted that GOB-IV data were only included for the design of the field assessment of RWHS and PSF. GOB-IV is a countrywide rural water supply project financed fully by GOB that is providing water supply facilities through the installation of shallow tubewells, deep tubewells, dug wells, pond sand filters and rainwater harvesting. This includes arsenic affected areas and, where shallow wells are affected, it is installing alternative options suitable for that particular area. Inclusion of the GOB IV DTW data in particular represented problems as these are not sunk as arsenic mitigation and therefore would be more likely to target areas with little or no arsenic, thus potentially biasing assessment of water safety.

Discussions on whether to include the GOB-IV DTW data centred on whether the provisions should be considered as arsenic mitigation or routine activities (and deciding which intervention fitted into which of these categories). This was compounded by the fact that the total number of water points was so enormous (e.g. >55,000 DTW), which would be likely to result in large numbers of GOB IV DTWs being included in the survey. In summary the prime reasons for not including GOB-IV data were:

- The criteria for GOB-IV DTW installation differ from DTW for arsenic mitigation and the majority of options are not installed as part of arsenic mitigation;
- The difficulty in establishing differences between provision of water points as a routine activity under GOB-IV rather than specifically for arsenic mitigation;
- The impact that these data had on cumulated numbers; and,
- Only DTWs sunk specifically for arsenic mitigation by DPHE-Danida were included.

The cluster surveying approach adopted requires that proportional weighting tables be constructed for each technology type. The table contains a total of 1524 DWs, 4434 DTWs, 458 PSFs and 2606 RWHSs that are grouped by Upazila. The selection of cluster is then carried out through random sampling.

The first stage is to randomly select a number between 1 and 1524 for dug wells, 1 and 4434 for DTWs, 1 and 458 for PSF and 1 and 2606 for RWHS. The next stage is to determine the sampling interval. The sampling interval (SpI) is determined for each technology type by dividing the cumulated total of supplies (T_c) for that technology (given in the proportional weighting tables) by the number of clusters (N) for that technology. The random numbers were obtained by a lottery method. The data for selecting clusters for each technology type is presented in Table 3.3.

Table 3.3: Data for selecting clusters for each technology type

Technology	**Tc**	**N**	**SpI**	**Random No.**
Dug Well, (DW)	1524	6	1524/6 = 254	130
Deep Tubewell, (DTW)	4434	6	4434/6 = 739	95
Pond Sand Filter, (PSF)	458	7	458/7 = 65	9
Rainwater Harvesting System (RWHS)	2606	7	2606/7 = 372	134

The clusters selected for DW, DTW, PSF and RWHS are shown in Tables 3.4, 3.5, 3.6 and 3.7 respectively.

Table 3.4: Clusters selected for dug wells

Cluster	District	Upazila	Programme	No. of DW	Cumulative DW
Cluster-1	Comilla	Daudkandi	BAMWSP	38	136
Cluster-2	Kushtia	Bheramara	BAMWSP	84	405
Cluster-3	Faridpur	Bhanga	DPHE-Unicef	49	661
Cluster-4	Madaripur	Rajoir	DPHE-Unicef	98	951
Cluster-5	Rajshahi	Charghat	WPP	11	1154
Cluster-6	Chapai-N'gonj	Gomostapur	WPP	71	1446

Table 3.5: Clusters selected for deep tubewells

Cluster	District	Upazila	Programme	No. of DTW	Cumulative DTW
Cluster-1	Chandpur	Faridganj	BAMWSP	98	158
Cluster-2	Noakhali	Begumganj	DPHE-Danida	1006	1814
Cluster-3	Lakshipur	Lakshipur Sadar	DPHE-Danida	633	2447
Cluster-4	Lakshipur	Raipur	DPHE-Danida	461	2908
Cluster-5	Feni	Sonagazi	DPHE-Danida	113	3114
Cluster-6	Barisal	Bakergonj	DPHE-Danida	410	4152

Table 3.6 Clusters selected for PSF

Cluster	District	Upazila	Programme	PSF	Cumulative PSF
Cluster-1	Pirozpur	Mottbaria	DPHE-Danida	3	
Cluster-2	Satkhira	Tala	AAN	5	
Cluster-3	Satkhira	Asasuni	DPHE-GOB-IV	21	
Cluster-4	Chandpur	Shahrasti	DPHE-Unicef	17	
Cluster-5	Barishal	Babugonj	DPHE-Unicef	8	
Cluster-6	Bagerhat	Moralgonj	DPHE-GOB-IV	11	
Cluster-7	Khulna	Paikgacha	DPHE-GOB-IV	35	

Table 3.7: Clusters selected for RWH

Cluster	District	Upazila	Programme	No. RWH	Cumulative RWHS
Cluster-1	Chandpur	Shahrasti	DPHE-Unicef	530	
Cluster-2	Noakhali	Noakhali sadar	DPHE-Danida	35	
Cluster-3	Comilla	Muradnagar	DPHE-Unicef	640	
Cluster-4	B.Baria	Nabinagar	DPHE-Unicef	231	
Cluster-5	Narail	Kalia	DPHE-Unicef	76	
Cluster-6	Faridpur	Bhanga	DPHE-Unicef	248	
Cluster-7	Rajshahi	Charghat	WPP	410	

The locations of the clusters are shown in Fig. 3.2.

3.2 Assessment of water quality and sanitary inspection

3.2.1 Water Quality Parameters

The two water quality parameters used as inputs into the quantitative health risk assessment models were arsenic and bacteriological quality. Thermotolerant coliforms (TTC) were analysed to represent bacteriological quality of water, as they are the most commonly used indicator bacteria. Selected positive samples were tested for *E. coli*. Additional samples were taken at 24 sites in Phase 1 and tested for somatic coliphage as a surrogate for viruses. A total of 13 physical and chemical water quality parameters that considered important for DTW and DW, RWHS and PSF water were also analysed in the field and laboratory. Analysis of all water quality parameters was also undertaken on samples from the STWs, selected from each cluster. Proper QA/QC was adopted in the analysis of all water quality parameters.

3.2.2 Sanitary Inspection

Sanitary inspection (SI) uses observation to assess the sanitary integrity and potential hazards in the environment that may affect water quality, particularly microbiological quality. Its use is well documented in the literature (WHO, 1997; Howard, 2002; WHO, 2004). It is generally used in conjunction with microbial analysis to understand the potential causes of contamination when it occurs, to assess the potential for contamination in the future and to develop control measures to improve microbial water quality.

Sanitary inspection form were prepared in the light of WHO Guidelines for Drinking-Water Quality Volume 3 (WHO, 1997) and adapted for DWs (with and without handpumps), DTWs, PSFs and RWHSs for use within RAAMO. They were piloted in the field by ITN staff who provided training for the local consultants prior to implementation of field work.

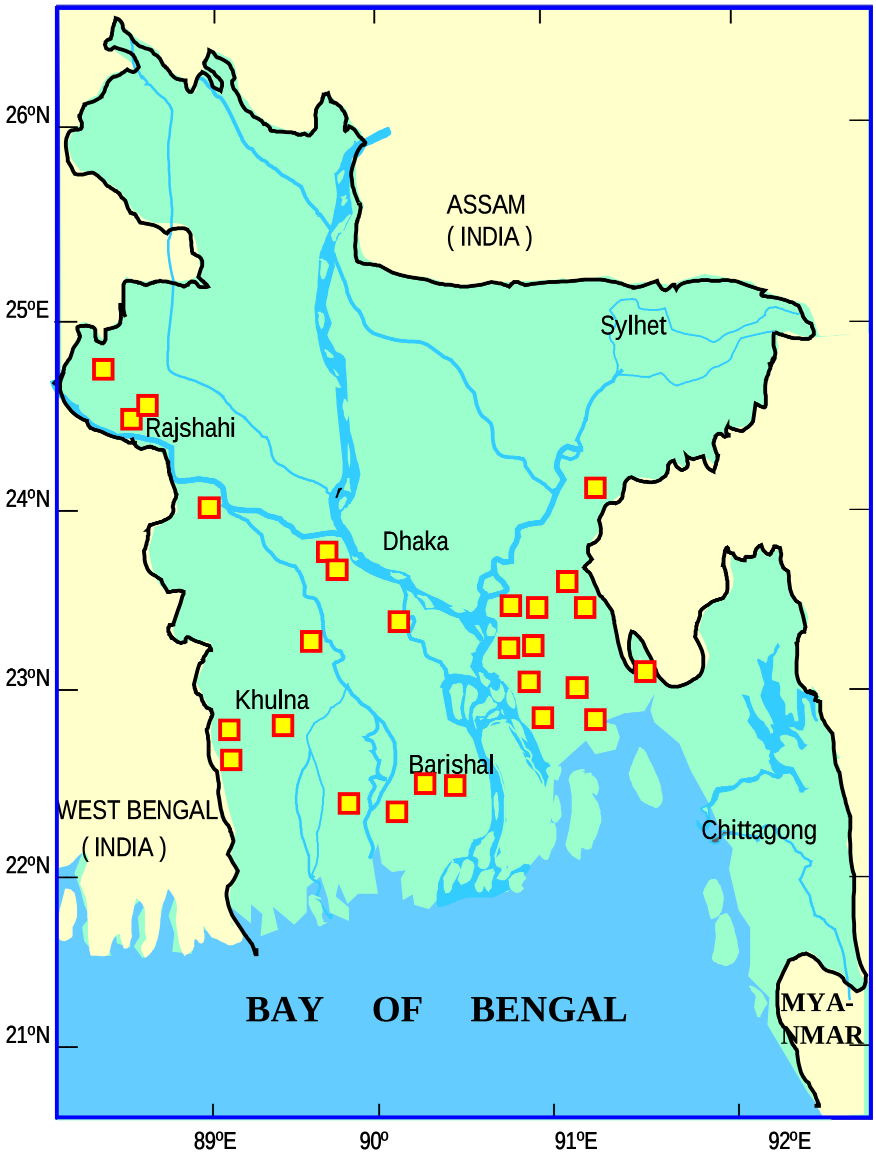


Figure 3.2: Location map of clusters

3.2.3 Data analysis

Water quality (field and laboratory) and sanitary inspection forms were analysed using both Sanman and SPSS. Data were analysed by technology type in relation to both Bangladesh Standards (BDS) and WHO Guidelines for Drinking-water Quality (GOB, 1997 and WHO, 2004). The data were used for the development of Quantitative Health Risk (QHRA) model and Water Safety Plan (WSP) for management of risk of water supply options for arsenic mitigation in Bangladesh.

3.3 Social assessment

3.3.1 Information needed

The first stage in undertaking the social assessment was to define the scope of the information required and to identify the key questions that were of importance. These were:

- General attitude among communities to sources with arsenic contamination;
- Estimate of the number of households using arsenic contaminated sources before and after testing results were provided;
- Measures, if any, people have taken (for instance how many households use contaminated sources before and after, results given by different groups if possible) and any changes in patterns of water use and time in water collection resulting from the mitigation options;
- Distance of the mitigation facility from the community and the perception of households regarding this;
- In case of continued use of arsenic contaminated water sources, assessment of the reason for such use;
- Information communities received on available technology options both in terms of content and language;
- Training, type and length provided in communities for managing the mitigation facility;
- Suggestions from communities for increasing the use of the mitigation options (if this is needed);
- Community preferences for different types of water source available (differentiate between very-poor, poor and non-poor as well as male/female);
- User perception of value of CBOs where they were formed and community action plans were developed;
- Review of the roles and responsibilities regarding water supply management in the community;
- Whether the community considers there to be any arsenic related problems or issues that are still unresolved or need to be addressed in the village; and
- Discussions with the support organisations and CBOs to assess impact of training to perform their respective responsibilities and assess performance of these agencies. This will also verify their involvement in the villages.

3.3.2 Desk Review

Relevant reports that discussed the social aspects of DWs, DTWs, PSFs and RWHSs were collected and reviewed. Unfortunately there are very few documents on social acceptability of different options, which makes comparison with the findings of this survey difficult. For instance, documentation produced by UNICEF, DASCOH and Dhaka

Community Hospital discuss at length the technical aspects of DWs, but make only passing reference to social issues. All the available documents conclude that DWs are socially acceptable in contrast to the views of some planners.

3.3.3 Selection and Training of Field Enumerators

The social assessment team selected two enumerators (a male and a female) with prior field experience in administering questionnaire survey. The team provided them orientation on the objective and methodology, and on-the-job training on respondent selection and administration of the tool during pre-testing of the questionnaire. The enumerators' field experience was useful in data collection and in developing and refining the questionnaire.

3.3.4 Development of the questionnaires

The questionnaires were designed to elicit answers on the key questions identified section 3.3.1. The DW, DTW and PSF are community facilities serving a number of households while RWHS is primarily a household option. The social assessment team therefore developed separate questionnaires for community and household units. Initial draft questionnaires were developed in English and translated into Bangla and were field-tested in communities using mitigation options. Following this field-testing the questionnaires were revised and expanded to ensure that all relevant information were obtained.

Following revision, the field team further pre-tested the questionnaire for relevance, consistency and language in communities using dug wells as a mitigation option in Paba and Charghat Upazilas of Rajshahi and Chapai Nawabganj districts. The PSF as a mitigation option was pre-tested in Shahrasti of Chandpur and RWHS in Charghat of Rajshahi district. The settlements patterns in rural Bangladesh are either clustered or linear along both sides of public thoroughfares. The settlements in Paba were linear and those in Sharasti and Charghat were clustered. On return from pre-testing the team reviewed in detail the results of the pre-test and further refined the questionnaire and produced a final version in Bangla. To the extent possible the team simplified the language of the questionnaire to improve ease in comprehension.

Information regarding quantity of water used for drinking and cooking was obtained through more informal group discussion with community members, as it was difficult for respondents to answer the question included on the questionnaire. Households with mitigation option close to their homes collected water in jugs and containers of different sizes and were unable to recollect the number of jugs/containers of water collected per day; those at some distance used pitchers of varying sizes.

Assessment of income status of households was another area of difficulty. The questionnaire included questions on occupation of head of households, ownership of services and facilities and observations on housing type. Many households had multiple income sources or earners. Though it is possible to formulate an income index that accounts for a variety of factors this was not possible within the scope of this assessment. From experience and discussion during pre-testing the team concluded that it would be sufficient to use community judgements of relative income status of a respondent household in that community. The enumerators therefore, were instructed to fill in the income status after discussion with people in the community.

3.3.5 Selection of respondents

In determining the number of respondents to be interviewed, it was assumed that each mitigation option was designed to serve 50 families, as set out in the requirements of the emergency response in the Implementation Plan for Arsenic Mitigation (GOB, 2004). From discussions with staff in mitigation programmes, this figure appears to be applied in a number of mitigation projects. However, it is recognised that some mitigation projects, such as DPHE-Danida, use a smaller number of families, typically 15-20.

The social assessment team administered the questionnaire survey to a 10% sample of households using the mitigation options provided to communities. Assuming an average of 50 households using one DW, DTW and PSF, 5 households per mitigation option were interviewed. The first household for interview was selected at random, the subsequent households were picked at an interval of 10 households in a systematic order. Since RWHS is a household option, all households having an operational RWHS among the selected samples were interviewed. The team noted that filling in one questionnaire took about 10 to 12 minutes. The problems encountered with different questions in relation to language, relevance, consistency and understanding were noted on the questionnaire. The team took notes on discussion with user community and community leaders.

The team selected adult women respondents by preference as the principal household water manager, but men and child over the age of 15 were also accepted. Should no adult or child over 15 be available in a selected household or be unwilling to respond the enumerators went to the next household. Women as respondent were given preference and more than 50% of the respondents were women.

3.3.6 Field Work

As households have no holding numbers there was no ready sampling frame. The team first identified the mitigation options, discussed with people who gathered around the options and assessed the number and location of households that draw water from the mitigation option. The first household was selected at random and then enumerators visited every tenth household in a systematic order; clockwise in the clustered settlement and left to right in the linear one.

Allowing for time to fill in the questionnaires, general discussion with people and community leaders and travel, data collection in no more than three communities was undertaken in one day. With inputs from the field enumerators the assessment team prepared a field work schedule. The schedule comprised a number of week-long field visits with time in-between to allow for team meetings in Dhaka to share experience and make mid-stream corrections and changes as necessary. The social assessment team leader also undertook field visits to check on fieldwork of enumerators and have discussions with user community and community leaders in selected communities. The team leader visited Bheramara, a community where mitigation has been provided by BAMWSP to have informal discussions with CBO leaders, community, Union Parishad Chairmen and representatives of Support Organizations (SO).

In every community a discussion took place prior to the start of the survey and towards the end of completion of every questionnaire to assess quantity of water used for drinking and cooking and income status of respondent households

3.3.7 Data Processing and Analysis

On completion of the fieldwork, the field enumerators retranslated the questionnaire and responses back to English. Numerical responses such as on age of respondents and household size were grouped into intervals. The data analyst coded the responses and processed them using SPSS. In some aspects, multiple responses were possible and therefore the total number of responses exceeds the total number of respondents.

Frequency distribution tables were produced and cross tabulations performed on some aspects such as on occupation by housing types and income status, ownership of services and utilities by income status and by housing types, user perception of distance by income status; use of water by distance from mitigation options; and user preference by income status.

4

WATER QUALITY AND SANITARY INSPECTION

4.1 Water quality

The microbial, chemical and physical quality of water of all water supply options were assessed in both dry and monsoon seasons. All PSF and RWH were tested in the monsoon season, but in the dry season samples could not be taken from 8 PSF and 18 RWHS because of lack of water. The results of all water quality analysis of the selected water sources are presented in Appendix 4. The maximum, median, mean and minimum values of water quality parameters of DW and DTW tested in dry and wet seasons under this study are given in Table 4.1 and 4.2 respectively, and those of PSF and RWHS in dry and wet seasons are given in Tables 4.3 and 4.4 respectively.

The median and mean values differ widely in almost all water quality parameters indicating that the data has a skewed distribution within the ranges of maximum and minimum values. In general the skew is leftwards, indicating the presence of outliers of high contamination which influence the average results. In the case of TTC analysis for DWs this was also due to fact that a default value of 1000 was set for samples that had counts *too numerous to count*. The median for TTC is therefore the value of principal interest.

Arsenic and microbial quality of water were given greater importance because of their greater influence on health outcomes. The TTC is usually presented in log scale and an arithmetic average of TTC can be greatly influenced by few extreme high values. A range of chemical parameters was tested in each technology. The same parameters were tested for DTW and DW. For PSF silica , boron, chromium were dropped, but analysis of algae included. Phosphate, iron, manganese, chromium and boron were not tested in water collected from RWHS as rainwater is not likely to be in contact with these contaminants. Rainwater may contain zinc and lead that can be leached out from the CI sheet roofing system used as rainwater catchment.

In the dry season, the median and mean values of TTC of DW water samples were 47 and 163 cfu/100mL respectively, while the corresponding values in case of DTW were 0 and 1 cfu/100mL respectively. This increases in the monsoon to 820cfu/100mL and 1998cfu/100mL for DWs. In the monsoon DTWs show slightly increased contamination as the mean if 11cfu/100mL, but the median remains 0cfu/100mL. The mean values of arsenic for DW and DTW in the dry season are 8.14 and 1.05 µg/L respectively and in the monsoon season the means is 3.72µg/L for DW and 1.25µg/L for DTW.

The median and mean values of TTC for PSF were found to be 37 and 91 cfu/100mL respectively in dry season and the values increased to 107 and 255 cfu/100mL in the monsoon season. The median and mean values of TTC for RWHS were found to be 2 and 14 cfu/100mL in the dry season, while those in monsoon season were 0 and 44 cfu/100mL respectively. Arsenic in water samples from PSF and RWHS was very low and the median and mean values were 0 and 0.55 µg/L respectively for both PSF and RWHS.

Table 4.1: Water quality of DW, DTW and STW in the dry season

Water Quality Parameters				Dug Wells				Deep Tubewells			
		WHO GV	BDS	Min.	Med.	Mean	Max.	Min.	Med.	Mean	Max.
Microbial	TTC cfu/ 100 mL	ND	0	0	47	163	TNTC	0	0	1	27
	E.coli cfu/ 100 mL)	ND	0	0	0	138	600	0	0	0.166	2
	Coliphage pfu/100mL	-	-	<1	<1	<1	<1	<1	<1	<1	<1
Physical	pH	-	6.5-8.5	6.9	7.1	7.14	8.2	6.6	7.1	7.21	8.1
	TDS (mg/L)	-	1000	373	900	968	2293	153	317	615	9167
	EC (µS/cm)	-	-	560	1350	1452	3440	230	475	922	13750
	Turbidity (NTU)	-	10	0.22	3.55	8.69	52	0.19	0.52	0.75	3.01
Chemical	Nitrate (mg/L)	50(NO_3)	10(NO_3-N)	<1.0	1.22	5.4	15	<1.0	.52	0.83	0.5
	Ammonia (mg/L)	1.5	0.5	<1.0	0.466	1.16	10	<1.0	0.52	0.83	8.0
	Phosphate (mg/L)	-	6.0	0.06	0.48	0.74	5	0.15	0.73	0.72	1.47
	Silica (mg/L)	-	-	13.1	21.1	25.56	48.3	20.3	47.9	44	63.9
	Iron (mg/L)	-	0.3 - 1.0	0	0.48	0.68	2.7	0.05	1.12	1.66	21.74
	Manganese (mg/L)	0.4	0.1	0.015	0.19	0.41	2.82	0.005	0.03	0.074	0.53
	Arsenic (ppb)	10	50	0	0.79	8.14	108	0	0.41	1.05	8.95
	Chromium (mg/L)	0.05	0.05	0.004	0.01	8.27	0.01	-	-	-	-
	Boron (mg/L)	0.5	1.0	-	-	-	-	0	0.1	0.1	0.2

TNTC- Too numerous to count; ND – Not detectable in any 100mL sample

Table 4.2: Water quality of DW and DTW in the monsoon (wet) season

Water Quality Parameters				Dug Wells				Deep Tubewells			
		WHO GV	BDS	Min.	Med.	Mean	Max.	Min.	Med.	Mean	Max.
Micro bial	TTC cfu/ 100 mL	ND	0	0	820	1998	15000	0	0	11	160
	E.coli cfu/ 100 mL	ND	0	0	445	657	3000	0	0	0	0
Physical	pH	-	8.5	6.9	7.1	7.14	7.5	6.7	7.1	7.13	7.7
	EC (∝S/cm)		1500	740	1380	1831	5920	36	465	946.83	14850
	Turbidity (NTU)	-	10	0.5	2.96	5.86	34.4	0.4	2.5	2.04	9.47
Chemical	Nitrate (mg/L)	50(NO_3)	10(NO_3-N)	0.5	0.75	4.10	15	0.05	0.05	0.05	0.05
	Ammonia (mg/L)	-	0.5	0	0.6	0.95	8	0.06	0.8	1.30	9
	Iron (mg/L)	-	0.3-1.0	0.01	0.1	0.4	2.4	0.01	0.95	1.65	19
	Arsenic (ppb)	10	50	0.01	0.55	3.72	25	0.05	0.05	1.25	6.6

TNTC- Too numerous to count, ND- Not detectable in any 100 mL sample

Table 4.3: Water quality of PSF and RWH in the dry season

Water Quality Parameters				Pond Sand Filter (PSF)				Rainwater Harvesting System(RWHS)			
	Parameters	WHO GV	BDS	Min.	Med.	Mean	Max.	Min.	Med.	Mean	Max.
Microbial	TTC cfu/ 100 ml	ND*	0	0	37	91	590	0	2	14	122
	E.coli cfu/100 ml)	ND*	0	0	2**	31	246	2	10	12	24
Physical	pH	-	6.5-8.5	7.00	7.55	7.66	8.70	6.8	10.75	10.02	12.2
	EC (µS/cm)	-		160	500	865	4800	30	95	245	1180
	Turbidity (NTU)	-	10	<5	<5	<5	<5	<5	<5	<5	<5
Chemical	Nitrate (mg/L)	50 (NO_3)	10 ($N\text{-}NO_3$)	0.05	0.14	0.25	2.5	0.17	0.50	0.62	1.4
	Ammonia (mg/L)	-	0.5	0.03	1.10	1.84	8.7	0.04	0.70	0.86	5.5
	Phosphate (mg/L)	-	6.0	0.11	0.30	0.45	1.78	-	-	-	-
	Iron (mg/L)	-	1.0	0.00	0.05	0.15	0.60	-	-	-	-
	Manganese (mg/L)	0.4	0.10	0.003	0.027	0.021	0.027	-	-	-	-
	Arsenic (ppb)	10	50	1.00	3.00	3.57	11.00	0	0	0.55	6
	Algae (mg/l)										
	Zinc (mg/L)	-	5	-	-	-	-	0.17	1.06	1.28	2.5

*ND: Not detectable in any 100 ml sample (WHO, 2004).
** Very small number of samples

Table 4.4: Water quality of PSF and RWH in the monsoon (wet) season

Water quality parameters				Pond sand filter (PSF)				Rainwater harvesting (RWH)			
	Parameters	WHO GV	BDS	Min.	Med.	Mean	Max.	Min.	Med.	Mean	Max.
Microbial	TTC cfu/ 100 ml	ND*	0	0	107	255	2200	0	0	44	640
	E.coli cfu/100 ml)	ND*	0	0	5	51	500	0	0	1.0	7
Physical	pH		6.5-8.5	6.7	7.6	7.51	8.4	6.9	9.65	9.33	10.9
	TDS (mg/L)	-	1000	87	253	459	5067	20	76.67	80.48	186.67
	EC (µS/cm)			130	380	689	7600	30	115	121	280
	Turbidity (NTU)	-	10	0.52	2.50	2.89	12	0.26	1.01	1.53	4.50
Chemical	Nitrate (mg/L)	50 (NO_3)	10 ($N\text{-}NO_3$)	0.50	0.50	0.65	4	0.05	0.05	0.18	2.0
	Ammonia (mg/L)	-	0.5	0.10	0.30	0.63	4.50	0	0.2	0.34	1.0
	Phosphate (mg/L)	-	6.0	0.10	0.25	0.30	0.99	-	-	-	-
	Iron (mg/L)	-	1.0	0.01	0.02	0.17	0.90	-	-	-	-
	Manganese (mg/L)	0.4	0.10	0	0.02	0.05	0.232	-	-	-	-
	Arsenic (ppb)	10	50	0.50	0.50	3.02	65.48	0	0	0.55	6.0
	Algae (mg/l)	-	-	0	0.61	0.91	3.30	-	-	-	-
	Zinc (mg/L)	-	5	-	-	-	-	0.08	0.35	0.63	1.96
	Lead (mg/L)	0.01	0.05	-	-	-	Nm	0	0.001	0	0.007

ND: Not detectable in any 100 ml sample (WHO, 2004).

The data obtained was analysed to see what proportion of samples from each technology met the Bangladesh Standards (BDS) for Drinking Water and WHO Guideline Values (WHOGV). In addition, data from other agencies was also included for comparison to the RAAMO data. Dhaka Community Hospital (DCH, 2003), Japan International Cooperation Agency/Asian Arsenic Network (JICA/AAN, 2004a&b), JICA-UNICEF (2005), Development Association for Self-reliance, Communication and Health (DASCOH, 2004) have conduced analysis of DW and DTW waters for assessment of quality.

The percentage of samples of DW and DTW waters exceeded the Bangladesh Standards (BDS) for Drinking Water and WHO Guideline Values (WHO GVs) for the major water quality tested are presented in Tables 4.5 and 4.6 respectively. The results of water quality analysis made by other organizations for DWs and DTWs are also included in the Tables 4.5 and 4.6.

Table 4.5: Dug well water exceeding BDS and WHOGV

WATER QUALITY PARAMETERS	**RAAMO Study : % DW Exceeding in**				JICA-UNICEF		DCH (DPHE-UNICEF)	
	Dry Season		Monsoon		% DW Exceeding		% DW Exceeding	
	WHOGV	BDS	WHOGV	BDS	WHOGV	BDS	WHOGV	BDS
Arsenic	25	3	12	0	23	4	5	3
TTC	94	94	83	83	12	12	74	74
Iron	-	23	36	12	-	26	97	82
Manganese	75	75	-	-	25	63	87	87
Ammonia-N	-	50	-	53	-	29	-	-
Nitrate-N	8	8	15	15	-	-	8	8
Turbidity	-	28	-	19	-	25	-	-
Colour	-	44	-	11		29	-	-
TDS	-	28	-	-	-	4	-	-

Table 4.6: Deep tubewell water exceeding BDS and WHO GV

Water Quality Parameters	**RAAMO Study : % DTW Exceeding in**				**JICA-UNICEF Study**	
	Dry Season		**Monsoon Season**		**% DTW Exceeding**	
	WHO GV	BDS	WHO GV	BDS	WHO GV	BDS
Arsenic	0	0	0	0	27	10
FC/TTC	8	8	47	47	1	1
Iron	-	58	-	43	-	21
Manganese	19	17	-	-	1	22
Ammonia-N	-	53	-	72	-	-
Nitrate-N	0	0	0	0	-	-
Turbidity	-	0	-	0	-	-
Colour	-	56	-	0	-	-
TDS	-	3	-	0	-	-

The data in tables 4.5 and 4.6 show that significant numbers of DWs in the RAAMO study exceed BDS and WHOGVs for key parameters For dug well, 94% of DWs exceed the recommended verification level on the WHO Guidelines for Drinking Water Quality (GDWQ) of an absence of TTC. Indeed, using the classification system of in the GDWQ, the DWs would be considered of to be poor quality (WHO, 2004). In the monsoon season, 91% of DW samples still exceed the BDS and the water would be classified as poor quality in the WHO system. Only 8% of DWs exceed the BDS and WHOGVs for arsenic in the dry season, in the monsoon none exceed the BDS and 9% exceed the WHOGV. A relatively high proportion of samples exceed the WHOGV for iron in the dry season, although performance in comparison to the BDS is better. Manganese , colour and turbidity are all significant problems in the dry season. In general, chemical quality of DWs improves significantly in the monsoon season.

For DTW, in the RAAMO study only 8% of samples the BDS for microbial quality and the water would be classified as of excellent quality in the WHO classification system. There are no samples exceeding the BDS or WHOGV for arsenic. Iron is the most significant problem, particularly in relation to the WHOGV, and problems are also found with turbidity and ammonia. In the monsoon season, 47% of RAAMO samples exceeded the BDS and the water would be classified as being of poor quality in the WHO classification. Chemical quality generally improved in the monsoon season.

The percentages of samples of PSF and RWH system exceeding the BDS and WHO GVs for the major water quality parameters tested are presented in Table 4.7 and 4.8 respectively. Japan International Cooperation Agency and United Nations Children Fund (JICA-UNICEF, 2005) conducted a survey of water quality of PSF and these are also compared to the BDS and WHOGVs in Table 4.7. The results of water quality analysis conducted by NGO Forum (2003) for RWHS have been compared with the findings of this study in Table. 4.8.

Table 4.7: PSF water exceeding BDS and WHO Guideline Values

Water quality parameter	**RAAMO Study: Percent PSF exceeding in**				**UNICEF-JICA Study: Percent PSF exceeding**	
	Monsoon season		Dry season			
	WHOGV	BDS	WHOGV	BDS	WHOGV	BDS
FC/TTC	95	95	97	97	0*	0*
Arsenic	2	2	3	0	25	0
Iron	-	0	-	0	-	0
Manganese	0	12	0	0	12	12
Ammonia	-	31	-	71	-	12
Nitrate	0	0	0	0	0	0
Turbidity	-	2	0	-	-	0

* Chlorination destroyed all TTC/FC

About 95 to 97% of the water samples collected from PSFs were found to be contaminated with TTC and few had arsenic and ammonia exceeding BDS for drinking water. Rainwater has a low mineral content. TTC was found in 43% of water samples collected from RWHS in wet season and the contaminated RWHSs increased to 63% in the dry season. The presence of ammonia exceeding BDS was found in 18% of the RWHS in wet season and in 71% of the systems in dry season.

Table 4.8: RWHS water exceeding BDS and WHO Guideline Values

Water quality parameter	RAAMO Study : Percent RWHS exceeding				NGO Forum Study: % RWHS Exceeding	
	Monsoon season		Dry season			
	WHOGV	BDS	WHOGV	BDS	WHO GV	BDS
TTC	43	43	63	63	24	24
Arsenic	0	0	0	0	-	-
Iron	-	-	-	-	-	0
Ammonia	-	18	-	71	-	-
Nitrate	0	0	0	0	-	-
Turbidity	-	0	-	0	-	0
Zinc	-	0	0	0	-	0

4.2 Microbiological quality

4.2.1 Indicator microorganizms

Thermotolerant coliforms (TTC) were analysed for water samples from all DWs DTWs, PSFs and RWHSs and E.coli was analysed in selected DW, PSF and RWHS samples.

4.2.2 Thermotolerant coliforms

Thermotolerant coliforms (TTC) were found in 94% of the DWs in the dry season and 91% in the monsoon season. The highest counts (TNTC) were all located in one Upazila (Gomastapur). Possible reasons for very high TTC count was that the water was raised from DW by rope and bucket. This method is more prone to contamination by users (hands etc) and therefore results in higher levels of contamination. The bacteriological quality of DW water reported by other organizations is compared with the level of contamination found in this study and presented in Figure 4.1.

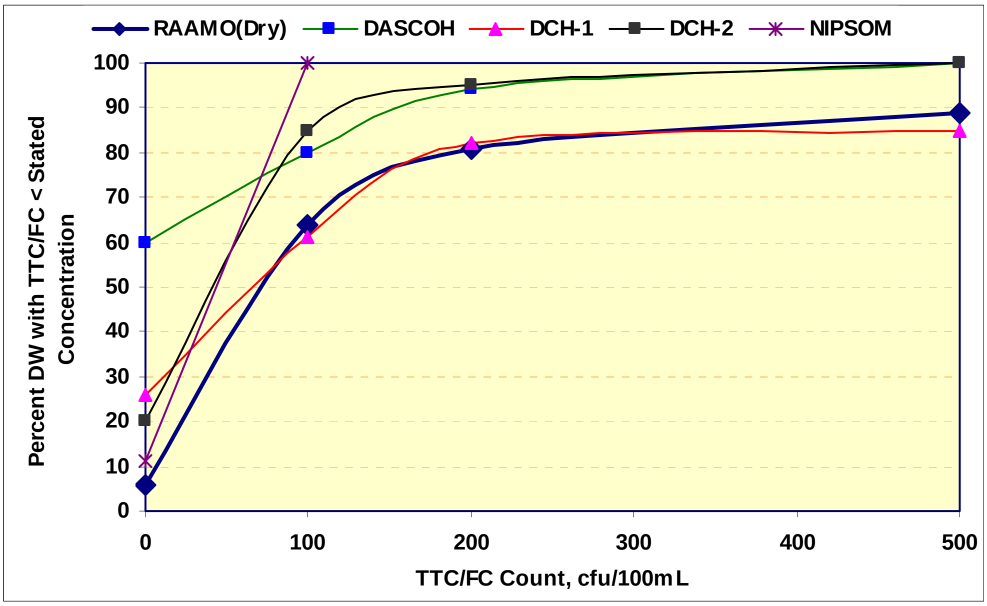


Figure 4.1: Comparison of level of bacterial contamination found in DW water

Figure 4.1 shows that the bacterial contamination of DW water found in this study is relatively high but comparable with a series of studies conducted by Dhaka Community Hospital in Sirajdikhan Upazila. Both the studies found a level of contamination exceeding 500 cfu/100mL in 10 to 15% of DWs with a highest value of 2000 cfu/100 mL, which indicates that there is significant faecal pollution and therefore risk of pathogen presence. All the studies noted above reported the presence of high level of bacterial contamination of DW water and most studies found only about 5-25% of DWs free from bacterial contamination.

TTC were found in 8% of the DTWs, the highest count (27 cfu/100ml) was found in Bakergonj In the monsoon season many more DTWs are contaminated and the highest count increased to 160 cfu/100mL from Raipur Upazila. Deep tubewells were expected to be free from microbial contamination. Possible reasons for the contamination of DTW identified are the poor sanitary condition at the tubewell and use of contaminated water for priming of the tubewell.

TTC were also found in 29% of STWs, with the highest count being 76 cfu/100ml. This indicates that STWs are vulnerable to contamination and it is likely that this is due to poor construction, in particular the lack of apron. Poor operation and maintenance and use of contaminated water for priming are also likely causes of the contamination identified.

The TTC in DW water found in dry season (Phase-1) and monsoon season (Phase-2) are presented in Figure 4.2. DW water becomes more highly contaminated in monsoon than in the dry season. In the dry season only about 3% water samples had a TTC count >500 cfu/100ml, while in the monsoon season 54% samples showed a count > 500 cfu/100ml. The inflow of polluted surface water in the monsoon season is likely to be the cause of such increase in the level of microbial contamination of DW water.

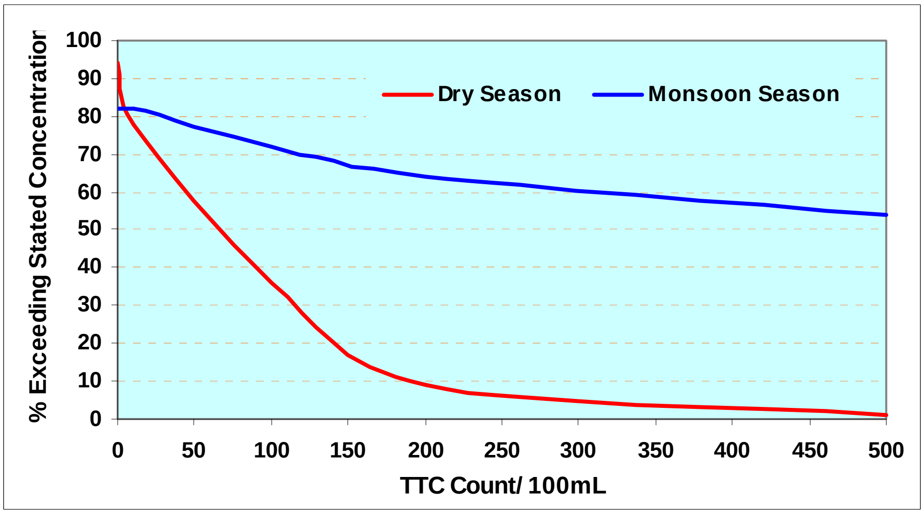


Figure 4.2: TTC in DW water in dry and wet season

Thermotolerant coliforms (TTC) have been found in 74% DWs by Dhaka Community Hospital (DCH, 2003), 40% by Development Association for self-reliance, Communication and Health (DASCOH, 2004), 90% by National Institute for Preventive & Social Medicine (NIPSOM, 2003), and in most of the DWs by Japan International Cooperation Agency/ Asian Arsenic Network (JICA/AAN 2004). The lowest contamination of only 7% DW water by faecal coliform was reported by JICA and UNICEF (2005). All the studies noted above reported the presence of high level of microbial contamination of DW water but this study (RAAMO) showed a much higher level of contamination of DW water in the monsoon season.

Dhaka Community Hospital has data from Serajdikhan from the dry season that shows DW contamination lower than the levels noted in this study, but the number of samples is small. A further study has been undertaken by Unicef and JICA in Jessore District in the dry season, which again showed that there are low levels of microbial contamination. However, the DW in the Jessore study had sand filters, which may also explain the reasons for better performance.

The microbial contamination of DTW water in the dry and monsoon seasons is compared in Figure 4.3. An increase in the level of contamination in DTW water is also observed in the monsoon season.. Secondary contamination mainly from priming of tubewell with polluted water and unhygienic practices are considered to be the sources of contamination of DTW, which clearly increases in the monsoon season.

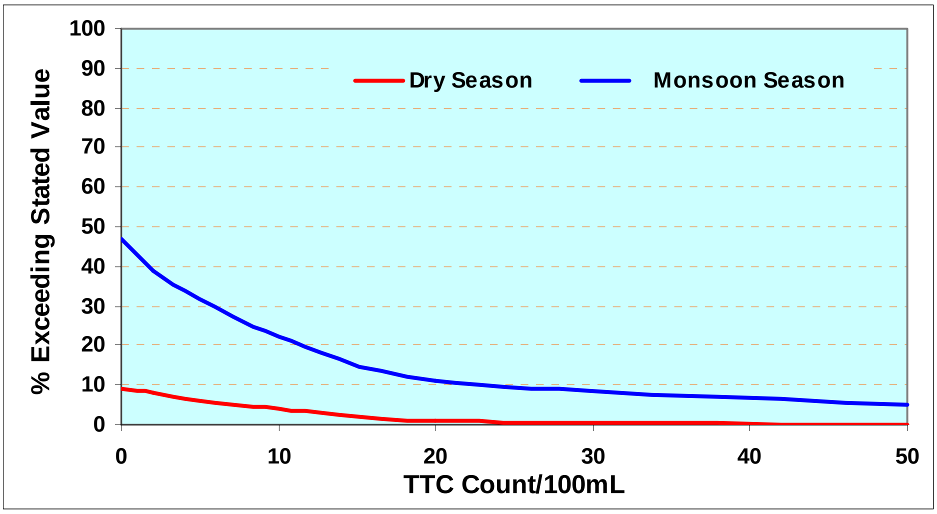


Figure 4.3: TTC of DTW water in Dry and Wet Seasons

Most PSF water in both the monsoon and dry season showed the presence of TTC (95 and 97.1% respectively). By contrast, in the monsoon only 42% water samples from RWHS showed the presence of TTC, which increased to 62.5% in the dry season. The average contamination (mean and median) of PSF is much higher in both dry and monsoon conditions than RWHS. All clusters of PSFs except Babugonj showed high TTC counts in the monsoon, the highest count being 2200 cfu/100ml in Morelgonj. The highest count in RWHS was found in the monsoon (640 cfu/100ml) in Charghat Upazila of Rajshahi district. The distributions of TTC in PSF and RWHS waters are shown in Figures. 4.4 and 4.5 respectively.

The sanitary inspection data reveals that existence of source of pollution or flow of polluting streams into the pond is the common phenomenon in the PSFs having high TTC count. The other significant factor is the use of pond for bathing and fish culture. The microbial population of the pond water was probably too high to be reduced by PSF to an acceptable level. The inadequate filter depth, poor operation and maintenance could be the other reasons for poor microbial quality of filtered water by PSF. A better sanitary condition is likely to be the possible reason for lower microbial contamination of PSFs in Babugonj.

The RWHSs in Kalia, Muradnagar and Nabinagar were found to be free from microbial contamination. The sanitary inspection reveals relatively few sanitary risks, which indicates a strong relationship between sanitary score and microbial contamination. The rainwater quality appears to deteriorate during the dry season, although there were some rainstorms during the sampling period. It is possible that some of the TTC identified are organisms that have grown inside the tanks. Research throughout the world has shown that regrowth of bacteria is not associated with gastrointenstinal disease (Hunter, 2001) so such organisms are of little sanitary significance. It is also possible that these organisms entered the tank from rain when the water from the first shower was not diverted (perhaps because of water shortages). If the latter is the case then the presence of TTC indicate an increased public health risk.

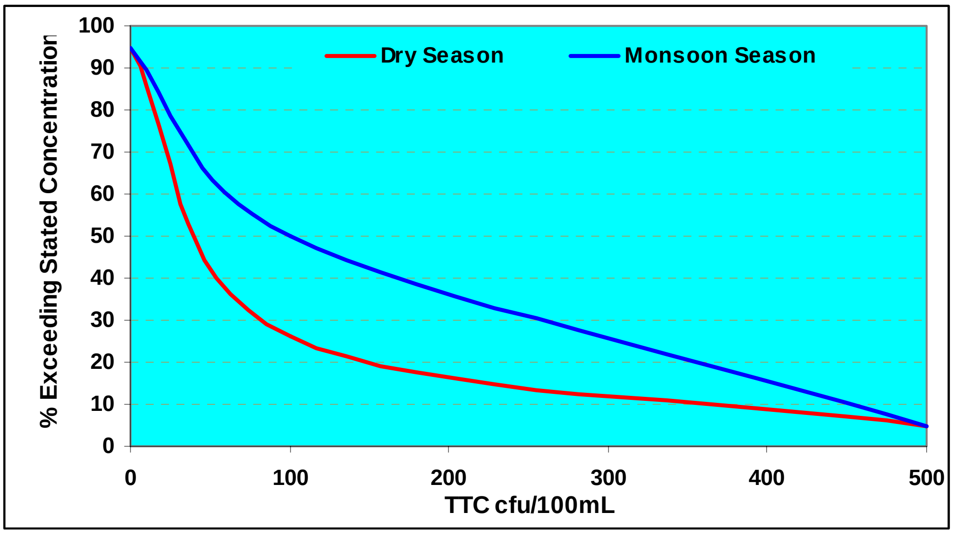


Figure 4.4: Microbial contamination of PSF water in dry and wet seasons

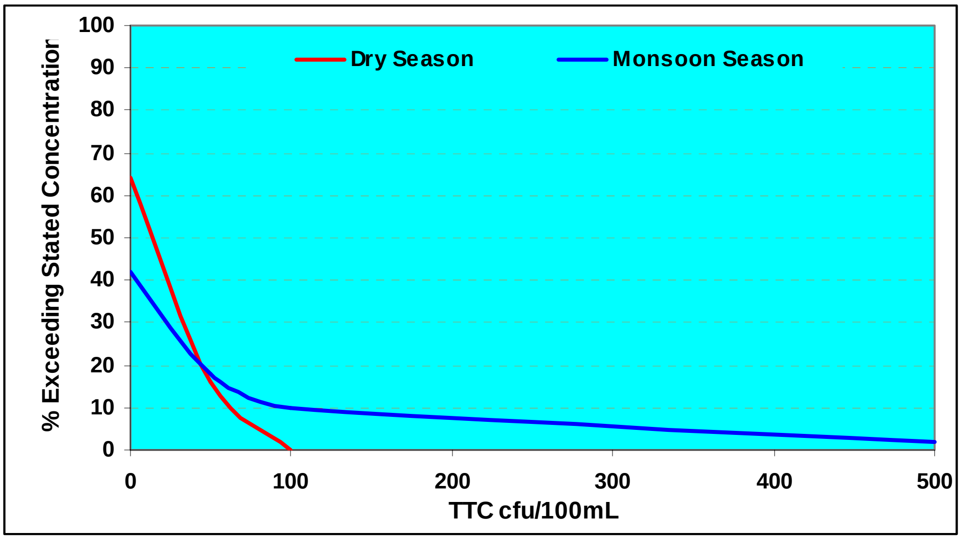


Figure 4.5: Microbial contamination of RWHS water in dry and wet seasons

4.2.3 E.coli

Confirmatory *E.coli* test was performed on selected samples of PSFs and RWHSs that were positive for TTC. In the monsoon, of 40 samples positive for TTC from PSFs, 19 were tested for *E.coli* and of these 13 showed presence of *E.coli*. In the dry season, 33 out of 34 samples were positive for TTC and 13 were tested for *E.coli*. Of these samples, 10 were positive for *E.coli*.

In the monsoon season, 18 out of 42 RWHS showed presence of TTC and seven samples were tested for *E.coli* and only one showed the presence of *E.coli*. In the dry season, 15 of the 24 samples taken were positive for TTC and four were tested and showed positive for *E.coli*.

The maximum value of *E.coli* for PSF samples in the monsoon was 500 cfu/100 mL and in the dry season 246 cfu/100mL. For RWHS is the maximums were lower at 7 cfu/100mL in the monsoon and 24 cfu/100mL in the dry season. The mean and median values of *E.coli* were lower for RWHS than PSF in the monsoon, but in the dry season the median value of RWHS was higher than for PSF, although the number of samples was very small.

Some random testing of *E.coli* was also undertaken for the DW and DTW testing in the dry season, although this was not directly confirmatory testing. The results show that a high proportion of TTC are likely to be *E.coli* and that those that are not are likely to be derived from faeces.

4.2.4 Coliphage

Analysis was also carried out for coliphage at the environmental microbiology laboratory of ICDDR,B as an index of potential viral breakthrough. There were no coliphage detected in any of the 24 samples of DW and DTW. This is likely to reflect rapid adsorption coliphage on intermediate clay minerals with charged sites. Somatic coliphages are an accepted surrogate for viruses (Ashbolt *et al.*, 2001) but in the context of clay rich soils, interpretation of the absence of coliphage in relation to absence of viruses requires some further consideration. Although the absence of somatic coliphage would suggest a reduced likelihood of viral presence, it is possible that some viruses may still be present in the water. Viral removal in clay-rich sub-surface environments depends in part of the isoelectric point of the virus (this is the point at which the electric charge on the virus changes, which affects whether it will be adsorbed onto positively charged clay particles). The isoelectric point varies with pH and therefore for certainty in interpreting the coliphage data, comparisons need to be made with the isoelectric of the somatic coliphage and those of viruses, which was not undertaken as part of this study.

4.3 Chemical quality

4.3.1 Arsenic

The concentration of arsenic in DW, DTW, STW, PSF and RWHS waters was measured by AAS in the laboratory. The distribution of arsenic in DW and DTW waters were compared in Figure 4.6.

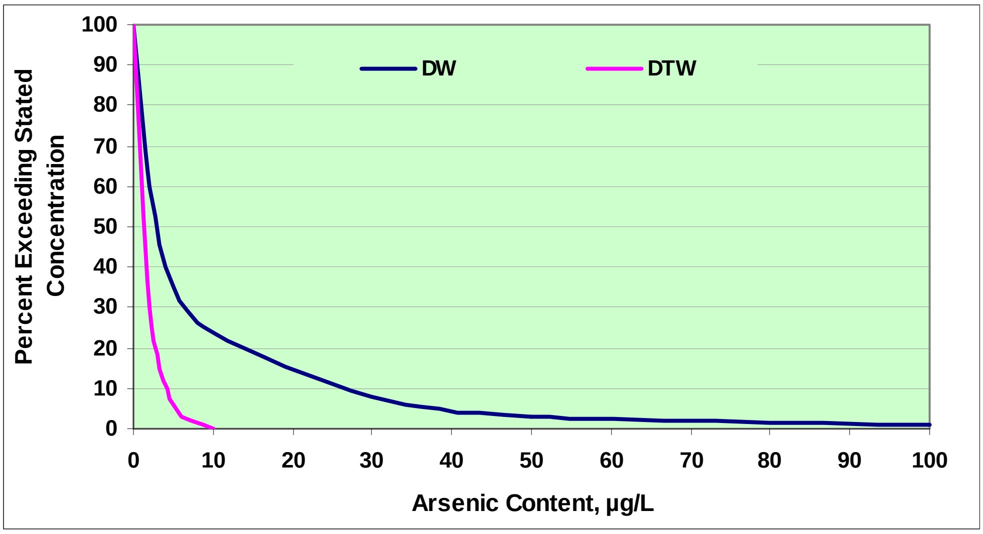


Figure 4.6: Distribution of arsenic in DW and DTW waters

In the DWs sampled, 3% exceeded BDS and 25% exceeded the WHOGV. The current study did not identify any DTW with arsenic content above BDS or the WHOGV for arsenic of 10 µg/L. However, arsenic contamination of DTW exceeding BDS of 50 µg/L was reported as 1% all over Bangladesh by BGS and DPHE (2001) and 10% in Sharsha Upazila by JICA/AAN (2004). The third party monitoring initiated by National Committee for implementation of arsenic mitigation also found 1% DTW contaminated with arsenic.

The distribution of arsenic contamination of DW water as reported by other organizations is presented in Figure 4.7. Arsenic contamination of DW found by this study was relatively low and compares well with the contamination level reported by DASCOH (2003) but lower than that found by DCH (2004) in Sirajdikhan Upazila, JICA/AAN(2004) in Sharsa Upazila and NIPSOM (2003) in Rajoir, Chapai Noabgonj and Saturia. The highest concentrations of arsenic in DW water was reported by JICA/AAN in Sharsha Upazila.

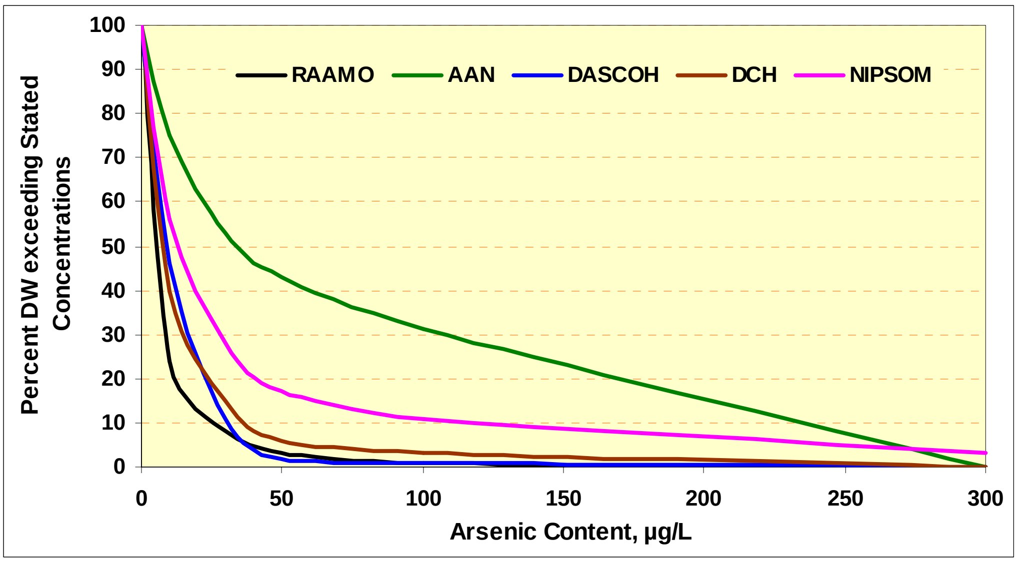


Figure 4.7 : Arsenic contamination of DW water

The findings of the current study is consistent with the data from other studies conducted on arsenic contamination of DW water, which shows that DWs can be arsenic contaminated and are not universally arsenic-safe. For instance 46% of DWs tested in 2003 in Sharsha Upazila had arsenic in excess of the BDS (AAN, 2004).

The distribution of arsenic is presented in Figures 4.8 and 4.9 respectively. The arsenic content of both DW and DTW waters reduced in the monsoon season.

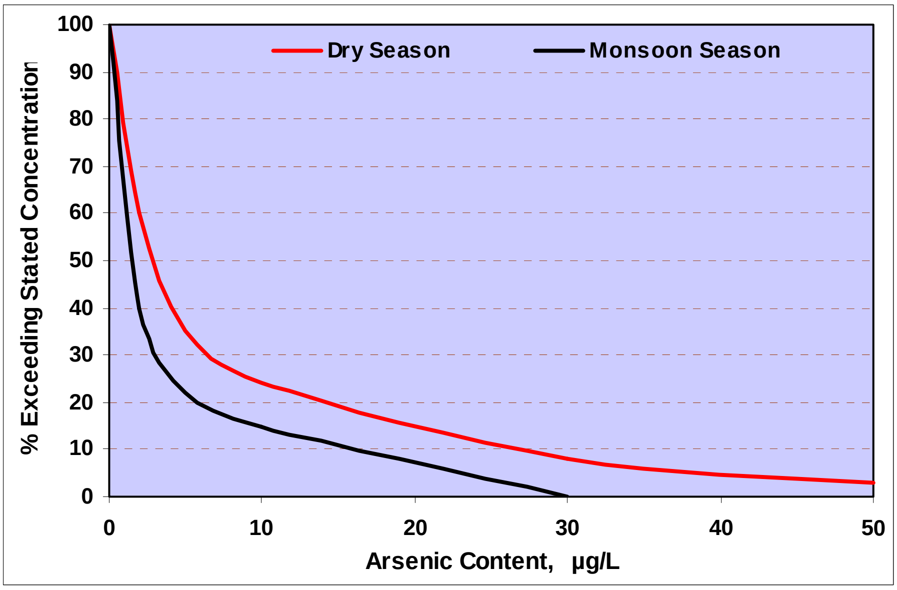


Figure 4.8: Concentration of arsenic in dry and monsoon seasons in DW water

The improvement of DW water in respect of arsenic content is significant. About 3% of DW samples showed an arsenic content exceeding BDS of 50 µg/L in the dry season while in the monsoon season arsenic content of all samples was within 30µg/l, lower than the BDS for arsenic. The percentages of samples exceeding the WHO provisional Guideline Value of 10µg/l were reduced from 24% in the dry season to 15% in the monsoon season. DWs collect water from the upper layer of the aquifers. Dilution of the top layer of water in the aquifer by infiltration of rain and surface water of low arsenic content may be the case of lower arsenic content of dug well water in the monsoon season.

Majed (2005) found that negative or very low Eh and low dissolved oxygen of DW water were not favourable for oxidation of iron, arsenic and odour producing substances. Small retention time due to high withdrawal of water and poor aeration due to smaller diameters of improved DWs may be the cause for insignificant deference between DW water and groundwater at the same level of depth. Whatever improvement in respect of dissolved minerals observed in DW water as compared to shallow tubewell water in the same location is due to dilution of water of the upper layer of aquifer by fresh recharges from surface and rainwater of low mineral content. There is hardly any difference between the quality of open and closed DW and the efforts made for keeping the improved DW open are futile.

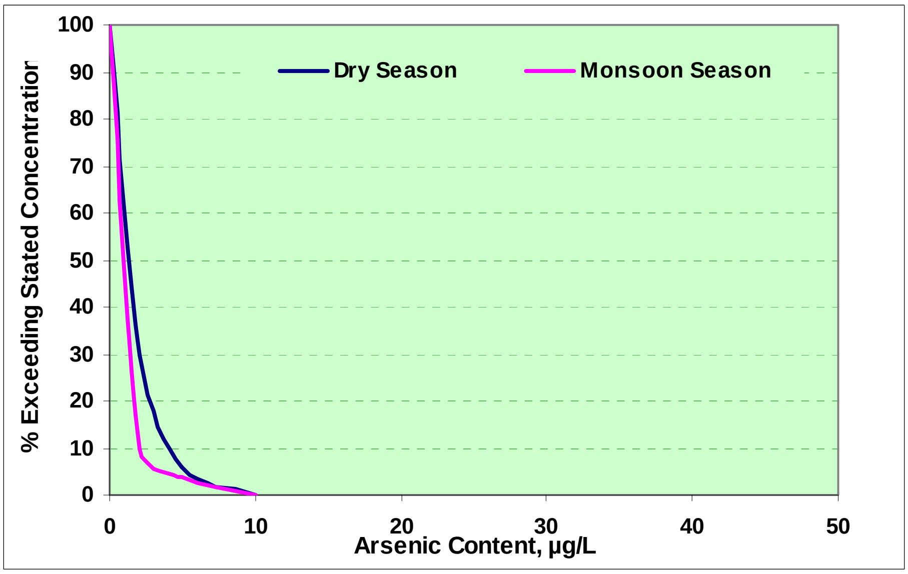


Figure 4.9: Dry and monsoon season arsenic concentration in DTW water

In the dry season, arsenic concentrations in waters of all the DTW sampled under RAAMO I were within 10µg/l. In the monsoon season some reduction in arsenic content of DTW water was also observed. The highest concentration of arsenic in DTW water was found to be 6.5µg/l.

The concentrations of arsenic in PSF and RWHS were low. The median and mean values of arsenic in water treated by PSFs are 0.5 and 3.0 µg/L respectively and those values of arsenic in water from RWHS were 0 and 0.55µg/L respectively. In the PSFs sampled, arsenic was found within 10 µg/l except one sample showing an arsenic content of 65µg/l. The PSF showing arsenic exceeding BDS is probably due to pumping water from a pond, which receives water from contaminated tubewell. About 60% of the samples from PSF showed an arsenic concentration below 1µg/L. About 25% of the samples of RWHS were analysed for arsenic. The concentration of arsenic in all but one sample was found below 1µg/L. Only one of RWHS sampled showed an arsenic concentration of 6 µg/L. The distributions arsenic on PSF and RWHS are shown in Figure 4.10.

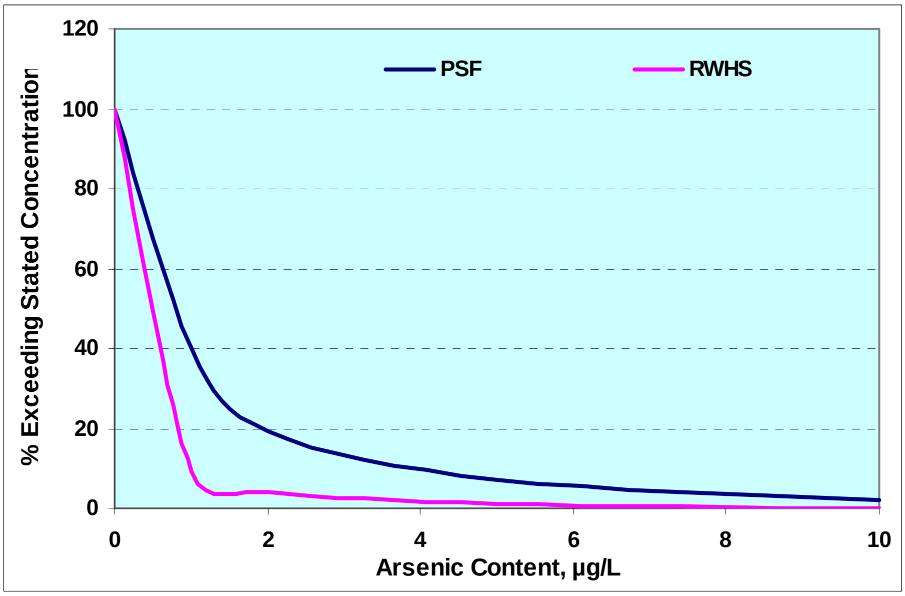


Figure 4.10: Distribution of Arsenic in PSF and RWH waters

The results of analysis of arsenic for PSF and RWHS samples indicates that arsenic content in both rainwater collected by RWHS and surface waters filtered by PSF are very low and most of the samples show a level below detection limit. It is consistent with the expectation that rainwater and surface waters are significantly free from arsenic.

4.3.2 Nitrate and ammonia

The main sources of nitrate in shallow aquifers are leachate from agricultural land and decomposing organic matter buried in soil or from pit latrines. The water quality analysis showed that the concentrations of NO_3-N in about 97% of the DW water and 100% of DTW water were within BDS of 10 mg/l for nitrate-nitrogen (NO_3-N). All STWs were within the BDS.

Ammonia contamination in DWs was observed on a larger scale. About 50% DWs contained NH_3-N above the BDS of 0.5 mg/L and 11% exceeded WHO GV of 1.5 mg/L. The median value of 0.47 mg/l is very close to Bangladesh limit. It was found that 53% of DTWs failed to meet the Bangladesh standard of 0.5 mg/l and 6% exceeded the WHO GV of 1.5 mg/L. Over 40% of STWs showed ammonia above the BDS, but none exceed the WHO GV.

It may be observed from Tables 4.1 and 4.2 that nitrate content of both DW and DTW reduced in the monsoon season and remained well within BDS value. However, a slight rise in ammonia contamination of DW and DTW was observed in monsoon season. Iron concentrations of DW waters reduced significantly in the monsoon season, while iron concentrations remained almost same in case of DTW.

The water quality analysis revealed that nitrate-nitrogen concentration in PSF water is higher than RWHS water but none of the PSF and RWHS waters exceeds BDS value of 10 mg/l for drinking water. The main sources of nitrate in surface water are surface drainage containing organic material or fertilisers and decomposing organic matter that naturally grow in surface waters. Application of manure and urea fertiliser used for fish culture are other sources of nitrate in pond water.

The WHO Guidelines for Drinking-Water Quality (2004) did not propose a health based guideline value for ammonia, as natural water does not contain ammonia exceeding the concentration significant for health. However, it is important from acceptability point of view. Ammonia contamination of PSF samples above the BDS was observed on a large scale. About 31% PSF samples contained ammonia above the BDS of 0.5 mg/l, the mean value of 0.63 mg/l is also higher than the Bangladesh Standard for drinking water. A concentration more than 3 mg/l indicates anaerobic activity in water (WHO, 2004). In the case of rainwater, the concentration of ammonia was lower than PSF water but 24% failed to meet the Bangladesh Standard.

4.3.3 Iron

No health based guideline value for iron has been proposed in WHO Guideline for Drinking-Water Quality (2004). Iron has no known effect on health, but a value above 2 mg/L could be avoided as a precaution against storage in the body of excessive iron.

However, excessive iron in water adversely affects aesthetic quality of water and may cause problems in other domestic uses of water.

The mean and median values for iron in DWs were lower than the BDS and only 23% of samples exceeded the BDS of 1 mg/L (see Tables 4.1 and 4.2). By contrast 58 % of DTW water exceeded the BDS for iron in drinking water and both the mean and median exceeded the BDS. The distributions of iron in DW, DTW and PSF are shown in Figures 4.11. All STWs exceed the WHO GV for iron and 87.5% exceed the BDS. Iron has no known effect on health, but adversely affects aesthetic quality of water and may cause problems in other domestic uses of water.

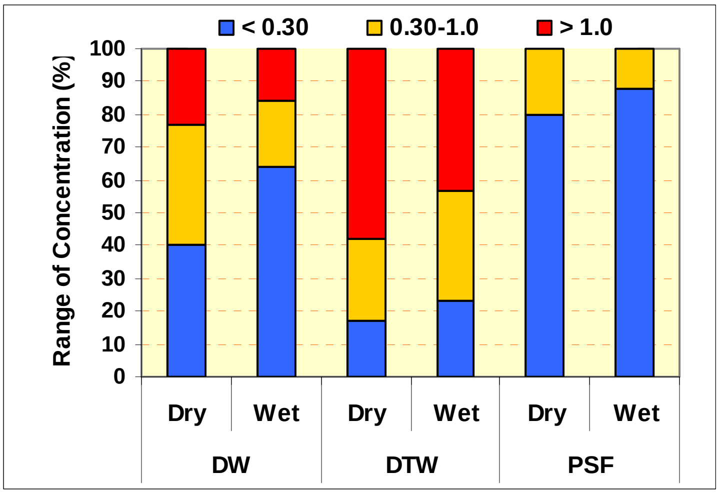


Figure 4.11: Distribution of iron in DW, DTW and PSF waters

None of the PSFs water exceeded the BDS of 1 mg/L for iron in drinking water. The mean and median values for iron were lower than desirable level of 0.3 mg/L in Bangladesh. The presence of iron in water from RWHS was not analysed. However, iron in rainwater may be present in small quantities when the CI sheet roof mainly used for collection of rainwater is corroded. However, the concentration in highly oxidized rainwater is expected to be very low.

4.3.4 Manganese

Manganese was present in all DW water in relatively high concentrations and both the mean and median values exceeded the BDS and WHO GLV of 0.1 mg/l. Manganese was present in all DTW water in lower concentrations. Although both mean and median values for manganese remained within the BDS and WHO GV for manganese, 19% of DTWs failed to meet standard. The majority of STWs (66.7%) also exceeded the BDS and WHO GV for manganese. The distribution of manganese in DW, DTW and PSF waters is shown in Figure 4.12.

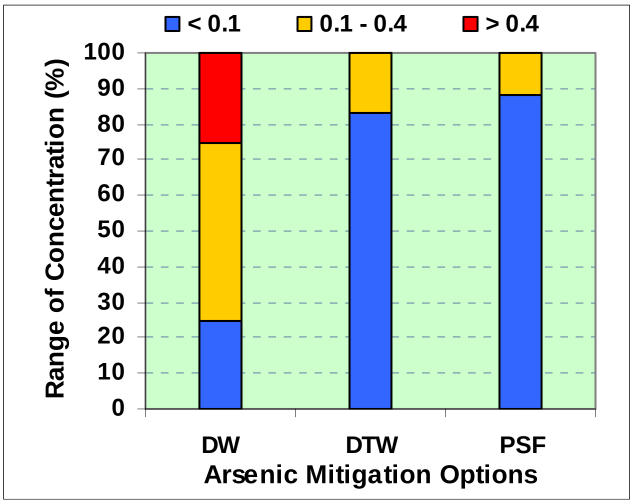


Figure 4.12: Distribution of manganese in DW, DTW and PSF waters

The presence of manganese is not common in surface water in Bangladesh. Therefore, 25% of the PSF clusters were tested for manganese. Only 12.5% of samples exceeded the Bangladesh Standard of 0.1 mg/L for drinking water but none exceeded the WHO Guideline Value of 0.4 mg/L. Both the mean (0.05) and median (0.02) values were within the BDS for manganese in drinking water. Manganese, in the absence of a known source, was not measured in water from RWHS.

4.3.5 Silica and phosphate

All samples from DW and DTW were tested for silica and phosphate. Both the water quality parameters have adverse effects on treatment of water particularly removal of arsenic from groundwater. The concentrations of phosphate in both DW and DTW waters were within BDS acceptable limit of 6 mg/l.

The concentrations of phosphate in PSFs waters were determined for all samples. The concentrations of phosphate for PSF waters were within BDS of 6 mg/l. Phosphate was not measured for RWHS.

4.3.6 Chromium and boron

The presence of chromium in selected DW water and presence of boron in DTW in the coastal area were analysed. The concentrations of chromium and boron were found to be within the acceptable limits of 0.05 mg/L for chromium and 1 mg/L for boron given in the BDS for drinking water.

4.3.7 Lead and Zinc

Since most of the catchments are zinc coated CI sheet and since lead may also be present in CI sheet, both lead and zinc were considered as possible contaminants in RWHS. However, it was not expected that either substance would be commonly found and thus only 15% of the samples were tested for zinc and lead. The test results revealed that both zinc and lead in RWHS water remained far below BDS and WHO Guidelines Value for drinking water.

3.3.8 pH

The pH value of all DW, DTW and STW water remained within Bangladesh standard value. No health based guideline value for pH has been established in WHO Guideline for Drinking-Water Quality (2004).

High pH values were observed in most of the water samples collected from RWH. The highest measured pH value was 10.9. The median and mean values were 9.65 and 9.33, higher that the acceptable highest level recommended in BDS for drinking water. The possible reason of such high pH value is leaching of calcium oxide from cement used for the construction of rainwater storage tank. However, the pH value of rainwater should improve as the storage tanks become older. The pH values in PSF water remained within BDS of 6.5 to 8.5 for drinking water. The median value was 7.6, which is close to neutral water.

4.4 Physical quality

4.4.1 Total dissolved solids

The total dissolved solids (TDS) and conductivity (EC) of DW, DTW, PSF and RWHS samples were measured in the laboratory. The TDS of DW was poor and the value of TDS exceeds the BDS and WHOGV in 28% cases. The variation of TDS and conductivity maintains more or less the same pattern. The TDS of DTW samples were relatively good. The value of TDS exceeds the Bangladesh standard in 3 % cases. The EC of STWs was similar to DWs. The TDS in PSF waters exceeded the BDS in 28% cases, while in all samples from RWHS, the TDS remained far below the BDS for drinking water. No health based Guideline Value for TDS or EC has been proposed in WHO Guidelines for Drinking-Water Quality (2004).

4.4.2 Turbidity

Although the mean and median values of turbidity were well within the BDS acceptable value of 10 NTU, 28% of DW water exceeded the acceptable value. The turbidity of DTW water was lower than that of DW water. Turbidity in STW was higher than DTW, but only 1 sample (4%) exceeded the BDS.

The water quality of both PSF and RWHS were very good in terms of turbidity. The mean and median values of turbidity were well within the BDS acceptable limit of 10 NTU. Turbidity in one sample of PSF water exceeded the BDS. The RWHS samples were very clear, showing the average turbidity around 1 NTU. In the WHO Guidelines for Drinking-Water Quality (2004) no health based Guideline Value for turbidity has been established but for acceptability to consumers, the turbidity of water should be below 5 NTU and below 0.1 NTU for effective chlorination.

4.4.3 Colour

Analysis of colour for water samples from DWs and DTWs was made by colorimetry in the laboratory and examined by visual observation in the field. About 44% of the DWs and 56% of DTW failed to meet Bangladesh standard for colour. Colour was noted as problematic in STWs, with 75% of samples tested exceed the BDS. High colour to water may be attributed to higher concentration of iron in water. High colour in water is important for the aesthetic quality of water.

Analysis of colour for selected water samples of PSF that appeared to be coloured on visual observation in the field, was performed through colorimetry in the laboratory. About 50% of the water samples brought to laboratory failed to meet Bangladesh standard of 15 TCU for colour in drinking water. Colour was noted to be a problem in water treated by PSFs. The mean and median values for color were 18.25 and 14 TCU respectively. High colour to water may be attributed to higher concentration of organic substances or algae in pond water. High colour in water is not acceptable to the consumers and may indicate pollution.

4.4.4 Odour

Odour was examined by smell in the field. The odour of water was generally not objectionable, except for a few DWs. JICA/AAN (2004) reported that 36% of the DW constructed in Sharsha Upazila in Jessore district produced water with little bad smell. The JICA study noted that smell in DW water appeared to vary from place to place and was probably related to the presence of organic matters in soil. About 22% of PSF water was found odorous, which was likely to be due to the presence of organic matters in pond.

4.4.5 Temperature

The temperature of water of DW and DTW ranged between 17°C and 25°C. The temperature of water in the PSFs ranged between 26°C and 31.5°C and between 24.5°C and 30°C for RWHSs.

4.5 Sanitary inspection

4.5.1 General

Sanitary inspection (SI) uses observation to assess the sanitary integrity and potential hazards in the environment that may affect water quality, particularly microbiological quality. Its use is well documented in the literature (WHO, 1997; Howard, 2002; WHO, 2004). It is generally used in conjunction with microbial analysis to understand the potential causes of contamination when it occurs, to assess the potential for contamination in the future and to develop control measures to improve microbial water quality.

Standard SI forms from the WHO Guidelines for Drinking-Water Quality Volume 3 (WHO, 1997) were adapted for DWs (with and without handpumps), DTWs, PSFs and RWHSs for use within RAAMO. They were piloted in the field by ITN staff prior to implementation of fieldwork. These SI forms are provided in Appendix 4.

4.5.2 Sanitary Risk Score

The sanitary risk scores (percent) of DW and DTW are presented in Figures 4.13. These indicate that for both DWs and DTWs, there are concerns regarding operation and maintenance and in particular risk management by communities.

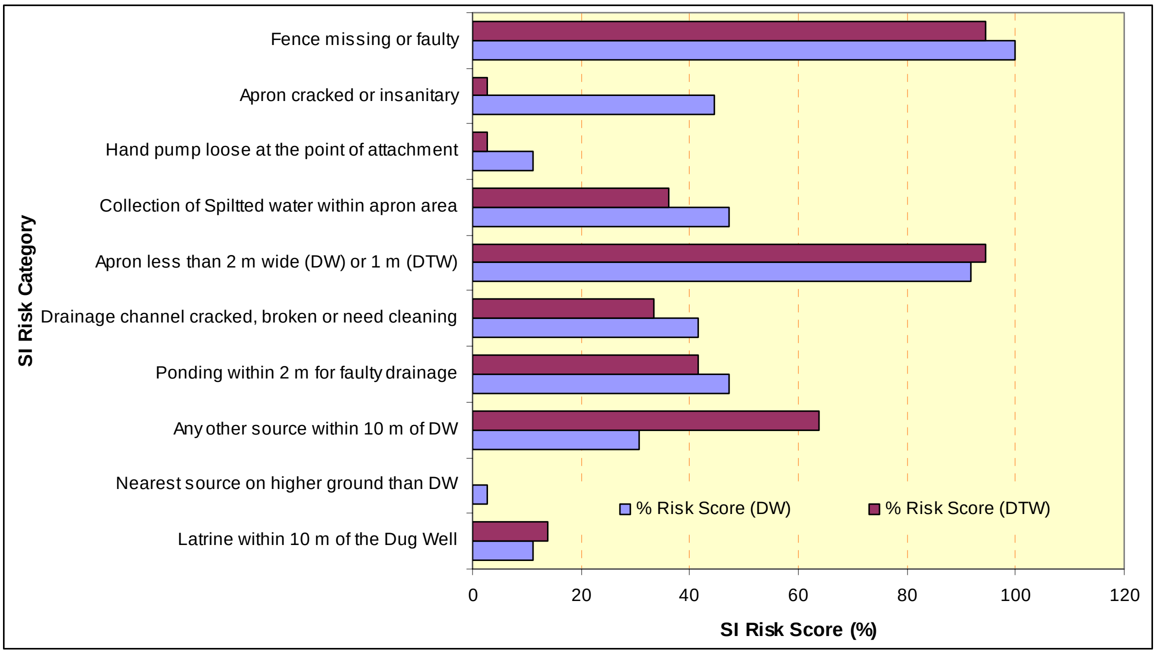


Figure 4.13: Risk factor frequency (%) of DWs and DTWs

The frequency of reporting specific sanitary risk factors (in percent) of PSF and RWH are presented in Figures 4.14 and 4.15 respectively showing the proportion of each factor. It is apparent from these figures that there are concerns regarding operation and maintenance for both the options. Good practices and risk management by communities are very important for safety of the drinking water sources.

The relative scores of DWs, DTWs, PSFs and RWHSs in order of risk value are compared in Figures 4.13 - 4.15. These figures show that there is some difference in reporting of individual risk factor

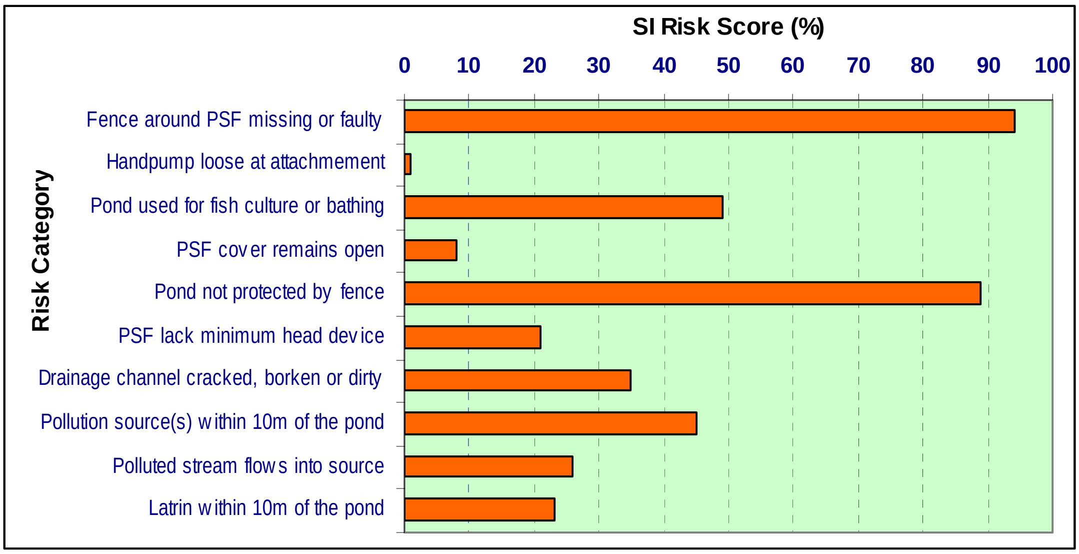


Figure 4.14: Risk factor frequency (%) of PSFs

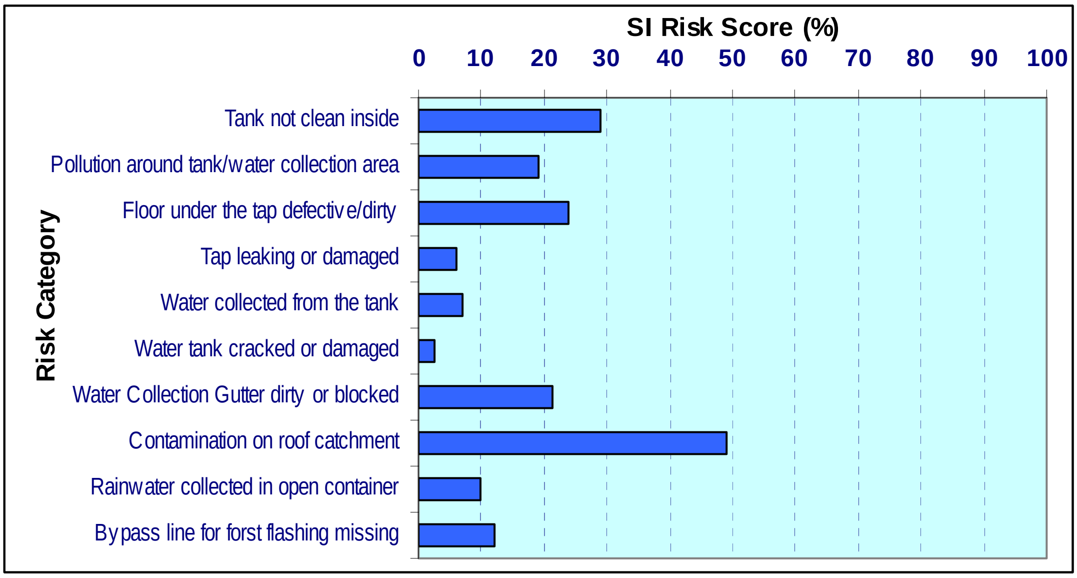


Figure 4.15: Risk factor frequency (%) of RWHS

Table 4.9 shows the 6 highest ranked risk factors for DWs, DTWs, PSFs and RWHSs. Among the risk factors '*fencing around water point*' is a socio-cultural issue. Fencing around a water point is generally desirable not only to prevent animals coming too close and causing damage to the water unit but also to prevent people to get bath and to wash cloths or utensils. The Phase-2 study reveals that the PSFs with unprotected ponds have poor water quality, particularly microbial water quality. In a number of countries the lack of fencing has been shown to be associated with deterioration in water quality. However, in Bangladesh, fencing may lead to misunderstanding among the users that collection of water is being restricted. Nonetheless the protection of the ponds is absolutely essential to preserve the desired quality of water.

Table 4.9: Ranked risk factors for DW , DTW, PSF and RWHS

Rank	Dug Well	Deep Tubewells	Pond Sand Filters	Rainwater Harvesting System
1	Missing fence	Missing fence	Missing fence	Visible sign of contamination on roof
2	Insufficient width of apron	Insufficient width of apron	Unprotected pond	Floor under the tap defective
3	Water ponding within 2m	Other potential sources of pollution	Pollution source within 10m of the pond	Gutter is dirty/blocked
4	Water collection in apron area	Water ponding within 2m	Cracked /faulty drainage system	Storage tank not cleaned inside
5	Cracked apron within 10m	Cracked /faulty drainage system.	Polluted stream flows into the pond	Pollution around the tank
6	Cracked /faulty drainage system.	Latrine within 10 m	Lack minimum head on filter bed	Bypass line or flush line missing

Insufficient width of apron occurred at many DW and DTWs. The lack of an apron of sufficient width may allow recharge of contaminated spilt water to enter the water source close to the ground surface and therefore with limited potential for attenuation. This may be a more pressing problem forDWs because as noted below, DTW are more robust with respect to microbial contamination. Since this issue is associated with cost and space, implementing agencies should consider this and try to prevent insufficient aprons being constructed in future programmes.

Water pooling within 2 m, *faulty drainage* and *cracked apron* all contribute to risks by creating a source of hazards and routes into the water source that reduce the potential for attenuation. They are also good indicators of whether operation and maintenance for water safety is being successfully implemented. Addressing these issues requires training and raising community awareness.

4.5.3 Sanitary risk score and water pollution

The water points with higher sanitary risk scores are likely to show high microbial counts, although this would usually be seen in the monsoon season. Figures 4.16, 4.17, 4.18 and 4.19 show the TTC counts versus risk scores of DWs, DTWs, PSF and RWHSs respectively. Both DTW and DW have a similar risk score, but the microbial quality of DTW water is much superior. Previous research has shown that there is unlikely to be direct linear relationships between TTC and sanitary risks (Lloyd and Bartram, 1991; Bartram, 1996; Howard, 2002a; Howard, 2002b; Howard *et al.*, 2003b). Typically, water quality would be categorised into broad categories (e.g. <1, 1-10, 11-50, 51-100, >100 cfu/100ml) and this shows a trend of increasing contamination with increasing sanitary risk. Similarly the sanitary risk scores and microbial quality of PSF and RWHS (Figures 4.18 and 4.19) cannot be linearly related. For detail analysis of the relationship of sanitary risks and water quality, much more data are required and other data such as rainfall needs to be factored into the analysis (Howard *et al.*, 2003b).

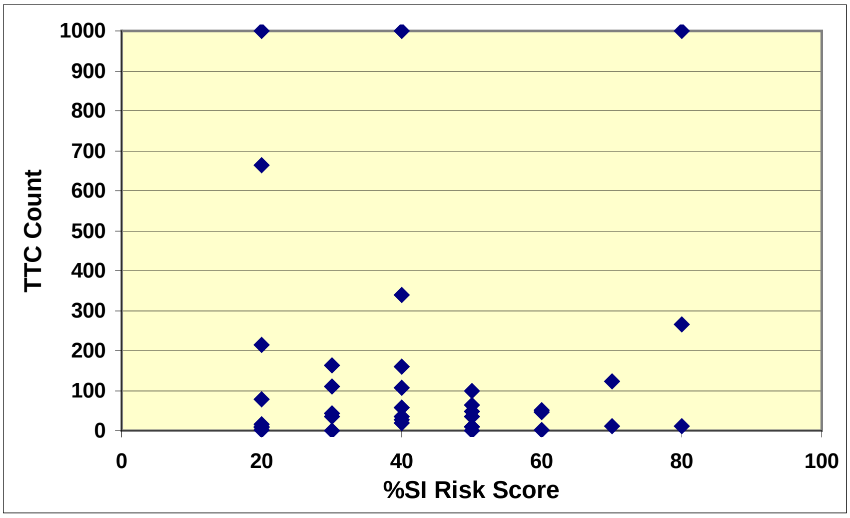


Figure 4.16: Correlation between TTC and SI risk score of DW

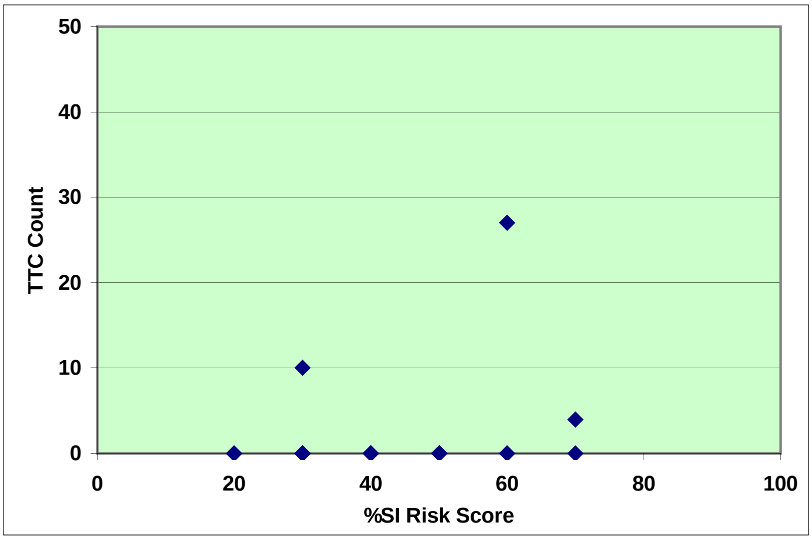


Figure 4.17: Correlation between TTC and SI risk score of DTW

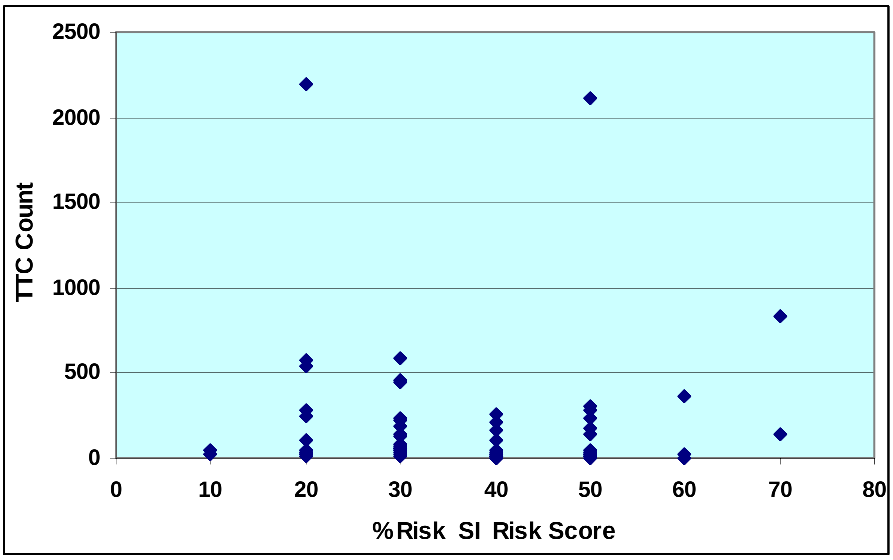


Figure 4.18: Correlation between TTC and SI risk score of PSF

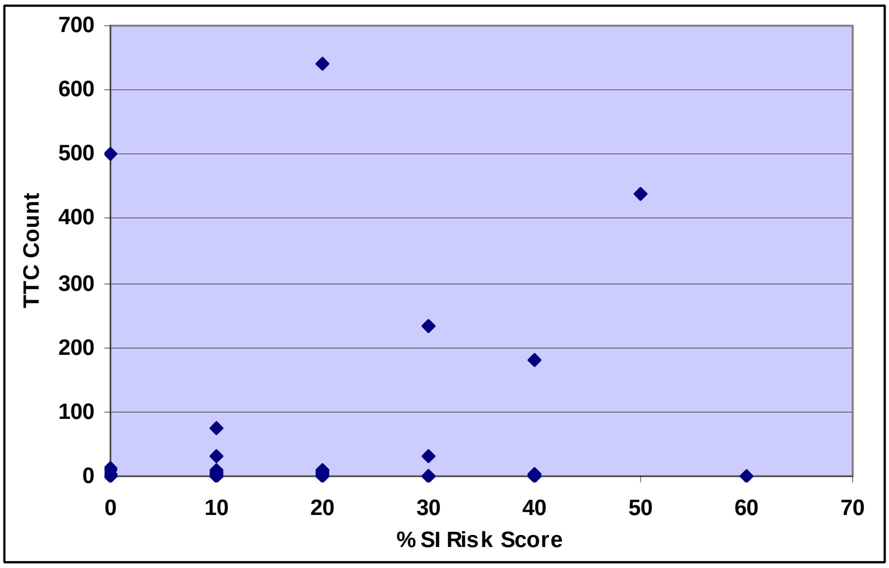


Figure 4.19: Correlation between TTC and SI risk score of RWHS

The data suggest that sanitary risk factors can be controlled through compliance with construction protocols, improved training of communities, raising awareness within the community, behavioural changes within the community and ensuring community participation in planning and implementation. For DWs it is also likely that control of microbial water quality requires disinfection, as discussed by DASCOH (2003).

The much better microbial quality of the DTWs despite a similar level of sanitary risk indicates that this technology is more robust with regard to microbial contamination. And microbial contamination should be very limited provided construction of well head is properly done. This is a finding that is supported from studies in other countries, for instance in Uganda boreholes with handpumps were found to be of good quality in most areas despite obvious risks (Howard, 2002b).

The worse microbial quality of the DWs suggests that these are more vulnerable to deterioration in operation and maintenance. The data suggests that in addition, single factors may be important in controlling contamination in some locations and this would warrant further investigation and repeat sampling.

The reduction in sanitary risks and maintenance of water quality require action by the water supply operators. This is most critical for DWs and PSF where even slight deterioration in operation and maintenance performance leads to increasing contamination. The high number of sanitary risks and poor microbial quality suggests that agencies providing DWs and PSF need to do more to support communities in maintaining their DWs and PSFs, if these are to provide safe water in the long-term.

The sanitary inspection data suggest that sanitary risk factors can be controlled through compliance with construction protocol, improved training of communities, raising awareness within the community, behavioural changes within the community and ensuring community participation in planning and implementation. For PSFs it is also likely that control of microbial water quality requires protection of pond, proper operation & maintenance (e.g. regular scraping the top sand layer, replacement of sand etc.) and disinfection.

4.5.4 Consolidated sanitary risk score

Sanitary Inspection provides an assessment of the existing sanitary conditions of the water point and quantifies the risks on a scale of 0 (no risk) to 10 (very high risk). The percentages of arsenic mitigation options under different SI risk score and corresponding risk category are shown in Table 4.10. The distributions of sanitary risk scores for arsenic mitigation options under RAAMO are presented in Figure 4.20.

Table 4.10: Distribution of total SI scores for dug wells and deep tubewells

RISK SCORE	RISK CATEGORY	% DW	% DTW	% PSF	% RWHS
0	No risk	0	0	0	24
1-3	Low risk	36	42	40	62
4-6	Intermediate to high risk	50	53	53	14
7-10	Very high risk	14	5	7	0

The overall sanitary conditions of the both DW, DTW and PSF as shown in Table 4.10 and Figure 4.20 were poor as compared to RWHS. The overall sanitary conditions of DTWs and PSFs were little better than those DWs. The mean and median sanitary scores for DWs were 4.28 and 4 respectively, while those of DTW were 3.97 and 4.00 respectively. These sanitary risk scores place both DWs and DTW in the intermediate to high risk category. About 24% of the samples of RWHSs do not pose a health risk and none fall into the category of "high risk".

In case of PSF, none fall into the category of 'no risk' while 53% and 7% of the PSF samples fall into intermediate and very high risk category respectively. The median value of sanitary score being 4, places PSF in the intermediate to high risk category while a median value between 1 and 2 places RWHSs in the low risk category. The mean value of sanitary scores for PSF and RWHS are 3.85 and 1.73 respectively.

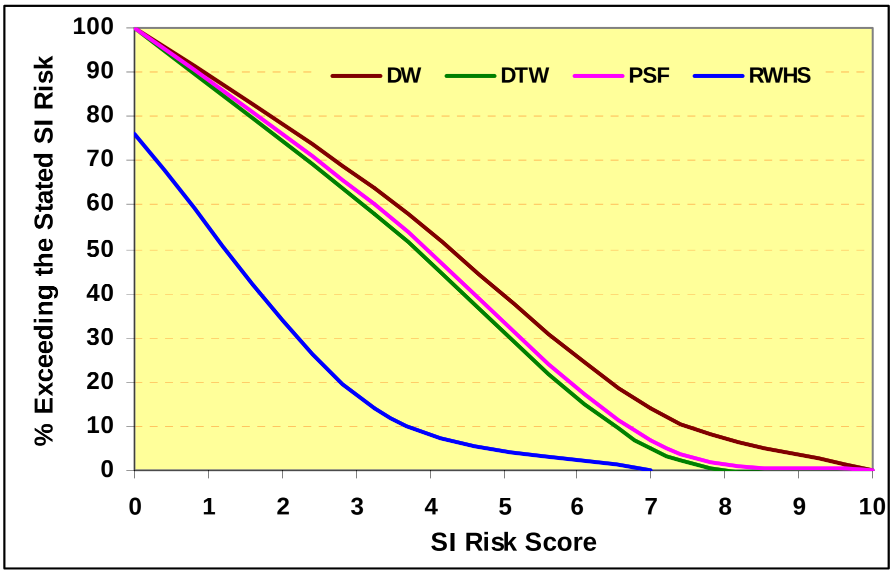


Figure 4.20 : Distribution of sanitary risk scores for arsenic mitigation options

Contamination of water in RWHS arises from secondary sources and sanitary protection can fully control the contamination from such sources. On the other hand, the surface waters may be so contaminated that PSF with sand filtration only cannot reduce the contamination to an acceptable level. Again, the efficiency of PSF is highly dependent on proper operation and maintenance of the system. The poor microbial quality of the PSFs suggests that these are more vulnerable to operating conditions which can be better controlled by introducing 'water safety plan' approach for water quality management. A single factor may be important in controlling contamination in some locations and identification of this factor requires further investigation and repeat sampling.

Sanitary risk is an important factor for the control of quality of water. The reduction in sanitary risks and maintenance of water quality require actions by both the community and the agencies providing water supplies. Like DWs, PSFs are also very sensitive to operation and maintenance and slight deterioration in performance may leads to increasing contamination. Therefore, the agencies providing PSFs need to provide support to the communities through training and at the same time the communities themselves also need to be more attentive in maintaining their own asset in order get safe water in the long-term.

4.6 Combined grading of water points

The grading of water in respect of microbial safety can be assessed jointly by microbial quality and sanitary inspection scores. The grading of water and action required in relation to microbial quality and sanitary inspection scores are presented in Table 4.11. Water showing good microbial quality at a point of time is not necessarily safe if the sanitary conditions are not good. It may be observed that even at very low *E-coli* count, urgent remedial action is needed if the sanitary inspection score is high.

Table 4.11 : Grading of water supplies according to microbial quality and sanitary inspection score (based on WHO, 2004)

E.coli Classification*	Sanitary Inspection Score →									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
E										
D										
C										
B										
A										
	No action	Low risk: low action priority			Intermediate to high risk: higher action priority			Very high risk: urgent action		

* E.coli classification (cfu/100ml): **A** (<1), **B** (1-10), **C** (10-100), **D** (100-1000), **E** (>1000)

Combined risk grading for DW and DTW for the dry and wet seasons are shown in Figure 4.21 and 4.22 respectively. Although microbial quality of DTW was good the sanitary inspection score had adversely influenced the combined risk grading of DTW. In the monsoon season about 55 percent of the DTW falls under intermediate to high-risk category while only 6 percent falls under very high risk category. On the other hand, 94 percent of DW in the wet season falls within intermediate to very high-risk categories with 85 percent under very high-risk category alone. Both microbial and sanitary condition contributed to this very high-risk situation of DWs.

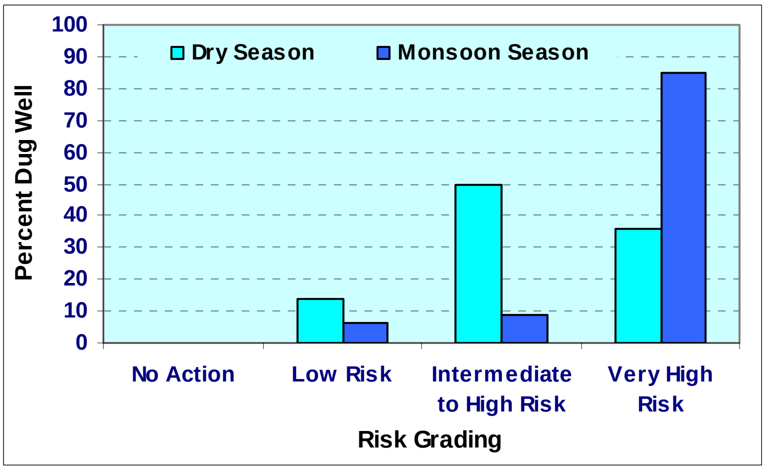


Figure 4.21: Seasonal variation of combined risk grading of DW

Seasonal variations of combined risk grading seem to be insignificant indicating that DTWs are less responsive to seasonal fluctuations. Figure 4.22 shows the seasonal variations of combined risk grading of DW. A sharp deterioration of DW based water system is evident from the very high risk grading of DWs in the wet season. About 50 percent of the DWs under "Intermediate to High Risk" category in the dry season dropped to only 9 percent in the wet season with the majority shifting to "Very High Risk" category. This indicates that DW based water system is much too sensitive with seasonal variations calling for a very strong and effective water safety plan to improve the situation.

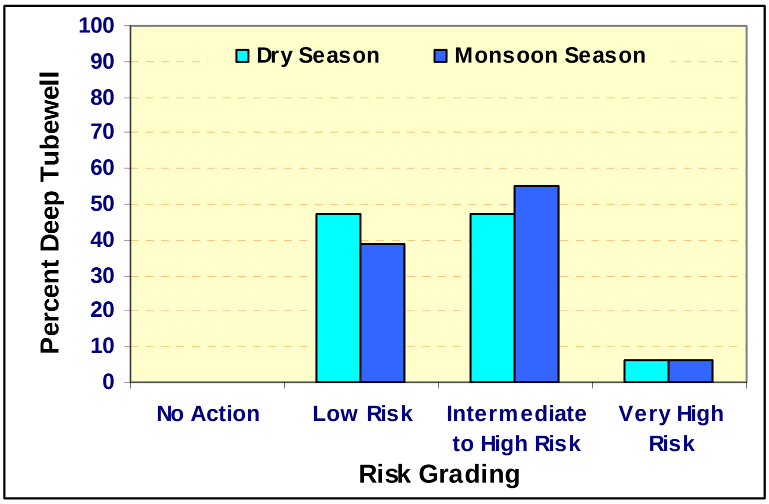


Figure 4.22: Seasonal variation of combined risk grading of DTW

Figures 4.23 and 4.24 show respectively the combined risk grading of PSF and RWHS during wet and dry seasons. It is observed that 95% of PSFs falls within intermediate to very high-risk categories while 50% under very high-risk category alone in the wet season. This evidence clearly depicts the need for an effective water safety plan to be in place to achieve a better sanitary condition and eventually the microbial quality of the waters from PSFs. As regard RWHS the combined risk is significantly lower than PSFs. About 38% in the wet season falls within intermediate to very high-risk categories with only 9% under very high-risk category.

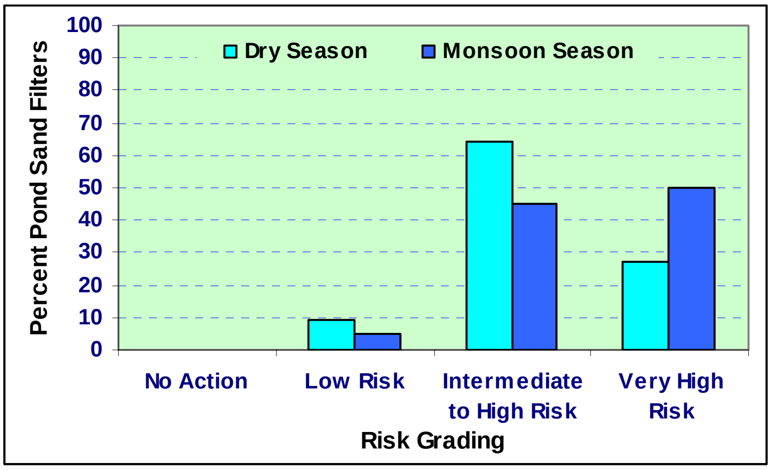


Figure 4.23: Seasonal variation of combined risk grading of PSF

Significant deterioration of waters of PSFs in wet season are evident. Water samples from about 64% of PSFs that fall under "Intermediate to High Risk" grading in the dry season dropped to about 45% and shifted to "Very High Risk" category in the wet season increasing the level to 50% from 27% in the dry season. Increased microbial contamination seems to be the primary cause of this deterioration.

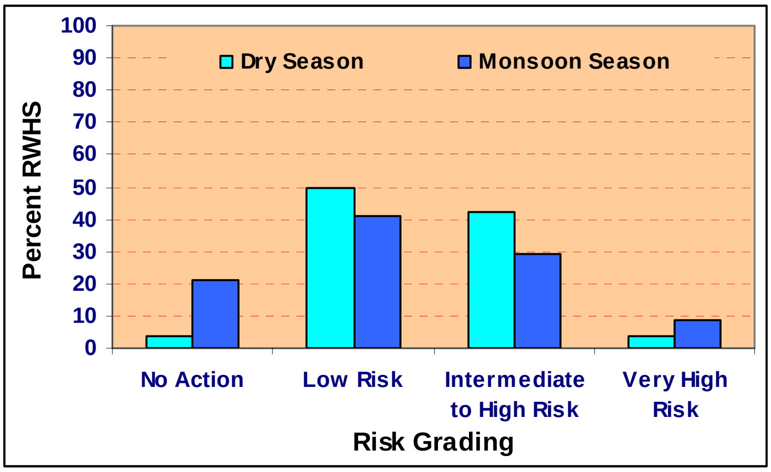


Figure 4.24: Seasonal variation of combined risk grading of RWH

The comparison of combined risk grading of water samples of RWHSs in the dry and wet season presented in Figure 4.23 shows that there is an increase in the "Very High Risk" category from 4% in the dry season to 9% in the wet season for water samples of RWHSs, by and large the water samples in these systems are found to be better in the wet season compared to that in the dry season. A reduction from 42% in the dry season to 29% in the wet season in the "Intermediate to High Risk" category has been observed.

5

SOCIAL ASSESSMENT

5.1 Introduction

This assessment addresses issues of social acceptability of DW, DTW, PSF and RWH and looks at the perception of communities on adequacy of these options. The assessment is based on the analyses of information and data from questionnaire survey and discussions with users of mitigation options, community leaders and members of CBOs and the findings, recommendations and conclusions upon review of existing documents and reports on DWs, DTWs, PSFs and RWHSs,. The assessment used both qualitative and quantitative methods and includes information from a wide section of communities using DWs, DTWs, PSFs and RWHSs as arsenic mitigation options. It is considered that although these findings have immediate relevance to the sample Upazilas, they would also be relevant to other communities in Bangladesh.

The methodology of the social assessment has been presented in detail in section 3.3. The social assessment was designed to acquire key information regarding the use of four alternative water supply options deployed for arsenic mitigation in Bangladesh. The questionnaires used were carefully designed to maximise the collection of key information. Social assessment was conducted on the households selected by random selection process within the command area of options already identified through cluster sampling discussed in section 3.1. The social assessment was conducted following water quality survey. The social survey was conducted on 178 households using DWs, 180 households using DTWs, 195 households using PSFs and 61 household using RWHS as arsenic mitigation options. The following sections present the results of social survey and recommendations made on the basis of the findings of social survey.

5.2 Results

5.2.1 Profile of respondents

The socio-economic profile of the respondents was recorded to be able to analyse differences between different socio-economic groups. Information on age, sex, family size, literacy and income of the respondents was used to make the socio-economic profile of the respondents. Figures 5.1 to 5.4 provide information on socio-economic aspects of the respondents. Seventy two percent of the respondents were women and 28 % men. The age of the respondents varied between 15 and 50 plus years with 84% in the 17-50-age group. Forty six percent of the respondents had household size between 6 and 10 members. Around 34 % of the respondents were illiterate, 61 % studied up to higher secondary level and only 5% had completed a graduation.

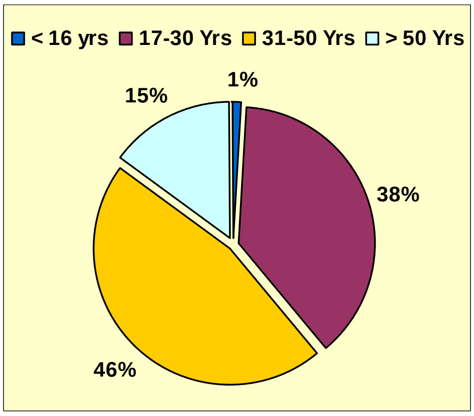


Figure 5.1: Distribution of age group of respondents

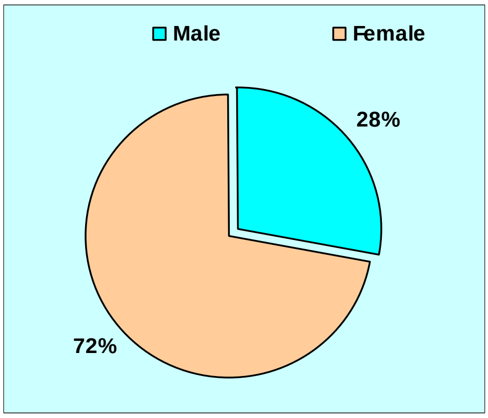


Figure 5.2: Distribution of gender

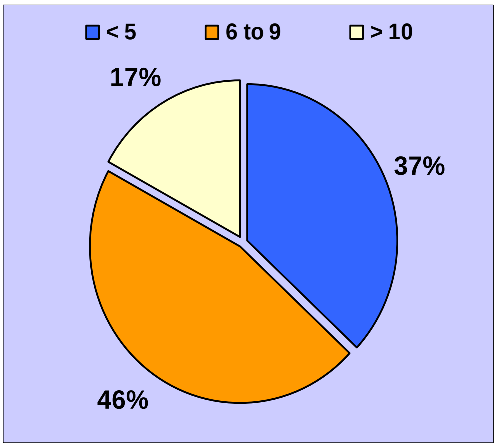


Figure 5.3: Distribution of family size

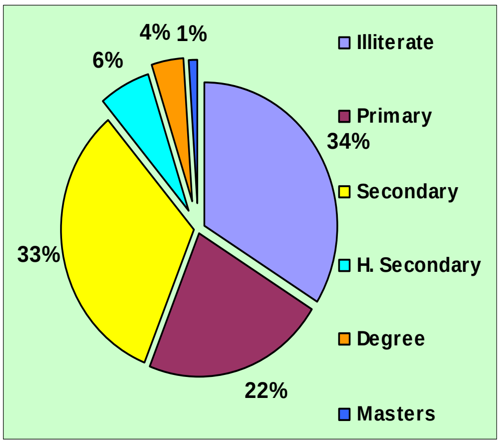


Figure 5.4: Literacy level of the respondents

The limited information that the survey provides does not allow a definitive answer on community profile with respect to economic status. The data showed limited relationship between perceived income status of respondent households identified by the communities with housing types or ownership of facilities/services such as television, radio, electricity or sanitary latrine. Cross tabulation of perceived income status by occupation and of occupation by housing type gives a slightly better association but not strong enough to make a conclusive statement.

Landless farmers, rickshaw/van pullers and day labourers correlate with community perception of income status, but do not all live in *kutcha* houses. It was not possible to develop a full socio-economic index in this survey and therefore in reporting on socio-economic status, this report uses community perception of income status of respondent households.

The breakdown of the 614 respondent households with respect to income and sex is provided in table 5.1.

Table 5.1: Family status and gender of respondents

Sex	Family Status							
	Poor		Middle Class		Rich		Total	
	Count	Percent	Count	Percent	Count	Percent	Count	Percent
Male	64	10	64	11	44	7	172	28
Female	249	41	133	21	60	10	442	72
Total	313	51	197	32	104	17	614	100

5.2.2 Location and perception of distance

The site selection and perception of distance for PSF differ greatly from those for DW and DTW. Location of PSF is governed by the presence of a pond suitable for installation of PSF while some common factors and criteria influence the location of DW and DTW. Hence, analysis of results of PSFs is done separately from DW and DTW.

Table 5.2 summarises the data collected regarding the process of site selection of the DW and DTW.

Table 5.2 : The process of site selection for DW and DTW

Process	Frequency	Percent
Through consensus of users	126	35
Volunteer of site for water point	15	5
Decision of HH that made the highest contribution	26	7
Through influential person or family	5	1
Others	136	38
Not known	46	13
Missing data	4	1
Total	358	100

In case of DW and DTW, the majority of respondents had knowledge of how the location for the mitigation option had been selected, although only about a third indicated that this was through community consensus. However, there was a marked difference in reporting of consensus as the means by which the location was selected between respondents using DWs and those using DTWs. Only 22% of households using DWs claimed ‘consensus’ while the figure among respondents using DTWs was 48%. This is because some of the dug wells provided were existing wells that had been rehabilitated (this comprised 15% of the DWs visited). This would have pre-empted decision on location making discussion on site selection redundant. Personal factors (in the form of contributions, influential position or volunteering of the site) were relatively unimportant in site selection. A large number of respondents gave diverse reasons classed as ‘other’ and this warrants further investigation.

The PSF users had little flexibility in choice of location of the water point. Ownership of ponds and willingness to offer them for PSF pre-empted the choice of location of PSF in 57% of cases (Figure 5.5). The poor seldom, if ever, own ponds that may be used for PSFs. An additional 32% of the sample households who paid a higher contribution towards the cost of PSF had a strong say in their location. The socio-economic reality in Bangladesh invariably biases choice of location for the PSFs towards the rich. However, there were no reports in the communities visited in the social assessment of rich or influential people denying poor access to water from PSFs.

The distance of PSFs from household are presented in Figure 5.6. About 15% of the respondents are within 50 meters of the PSF, 18% between 51 and 100, 46% between 101 and 300 meters and the remaining above 300 meters. However, it is not solely physical distance that is important, users' perception of distance is also important when judging acceptability. The data on user perceptions of the acceptability of the distance of the mitigation option are presented in Table 5.3.

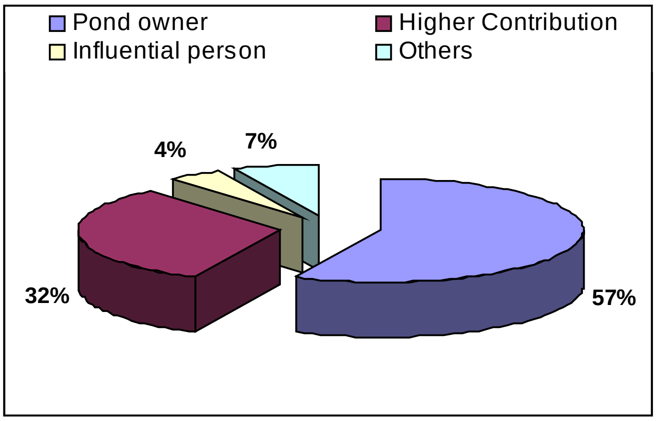


Figure 5.5: Factors in selecting location of

Sixty nine percent of the PSF users consider the water point as being near with only 5% expressing a contrary view. The RWHs was mostly within the courtyards of the respondents except for a few who shared the facility of neighbours and relations. The locations of the mitigation options were acceptable to a majority of the households using the options.

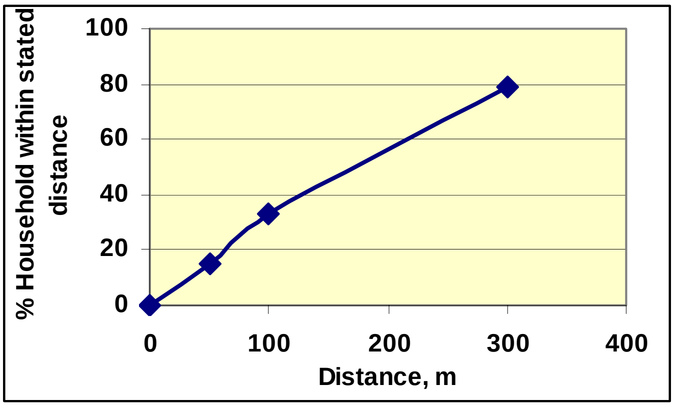


Figure 5.6: Distance of PSFs from households

In assessing the acceptability of a mitigation option, the acceptability of the distance of the mitigation option are presented in Table 5.3.

Table 5.3: Perception of distance by income status

Water Supply Options	Family Income Status	Perceived Distance, % of Total HH (% of Income group)			Total
		Near	**Acceptable**	**Far**	
Dug Well and Deep Tubewell	Poor	32 (55)	20 (35)	6 (10)	**58 (100)**
	Middle-class	13 (45)	13 (45)	3 (10)	**29 (100)**
	Rich	5 (39)	5 (39)	3 (22)	**13 (100)**
	Total	**50**	**38**	**12**	**100**
Pond Sand Filter	Poor	30 (60)	18 (36)	2 (4)	**50 (100)**
	Middle Income	25 (74)	7 (21)	2 (5)	**34 (100)**
	Rich	14 (88)	1 (6)	1 (6)	**16 (100)**
	Total	**69**	**26**	**5**	**100**

Convenience is one of the factors that is likely to influence the use of mitigation options and the number of purposes for which households use the water from the mitigation options. The data indicate that the majority of respondents in case of DW and DTW considered the distance to the mitigation option to be acceptable and 50% of all respondents perceived the distance to the mitigation option to be near. Relatively few respondents (only 12%) considered the mitigation option to be far from their home. Poor families generally considered the mitigation option to be near or an acceptable distance from their house. A slightly lower proportion of middle-class families considered the option to be near or an acceptable distance from the house but much fewer considered this to be far. It is within the group considered to be rich that a higher proportion of families considered the mitigation option to be far from their home and these made up 22% of families considering the option to be far, despite overall rich families constituting only 13% of the sample.

In settlement patterns characterised by an intimate mix of different income categories of households it is not possible to satisfy every income group in terms of distance of mitigation options from their homes. What is important is that, location of mitigation options does not create inconvenience to the majority of households expected to use a facility. The data suggest that in general this is being achieved in mitigation options.

Fifty percent of all users of PSFs considered them to be near or and further 38% considered the distance to be acceptable. Among poor households, 60% considered the PSF to be near and only 4% considered the PSF to be very far. More middle income and rich households (74% and 88 % respectively) considered to the PSF to be near, probably because of the fact that the ponds for installation of PSF were contributed by middle income and rich households.

5.2.3 Shift to mitigation options

The respondents were asked about the sources of water they used including use of red and green shallow tubewells for drinking and cooking purposes before and after installation of the mitigation option. It was found that many of the respondent households used multiple sources, which included rivers/ponds, green and red tube wells and old dug wells before the installation of the mitigation options. However, efforts were taken to identify the household using water from red tubewells and their shift towards newly installed alternative water supply options. It was observed that the people sometimes used water from green shallow tubewells (STW) from distant sources and sometimes used other sources. Hence these two groups were enumerated in one category. The shift in water use in the areas where DW, DTW, PSF and RWHS were installed are presented in Figures 5.7, 5.8, 5.9 and 5.10 respectively.

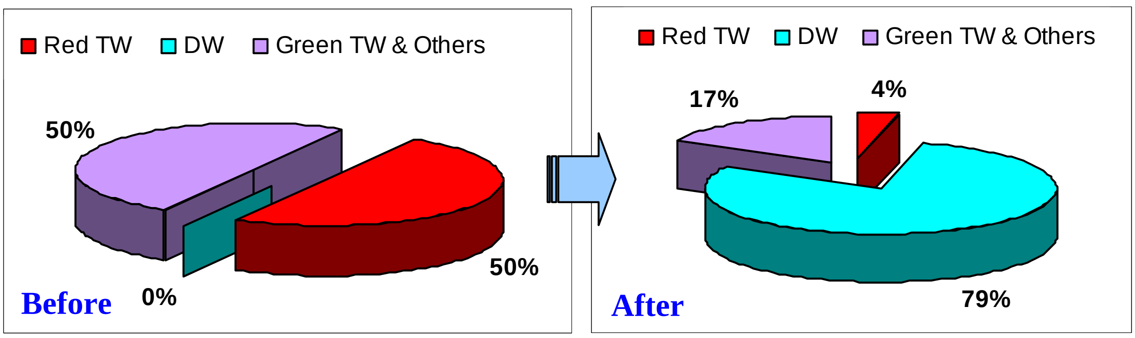


Figure 5.7: Shift in water use pattern before and after installation of DW

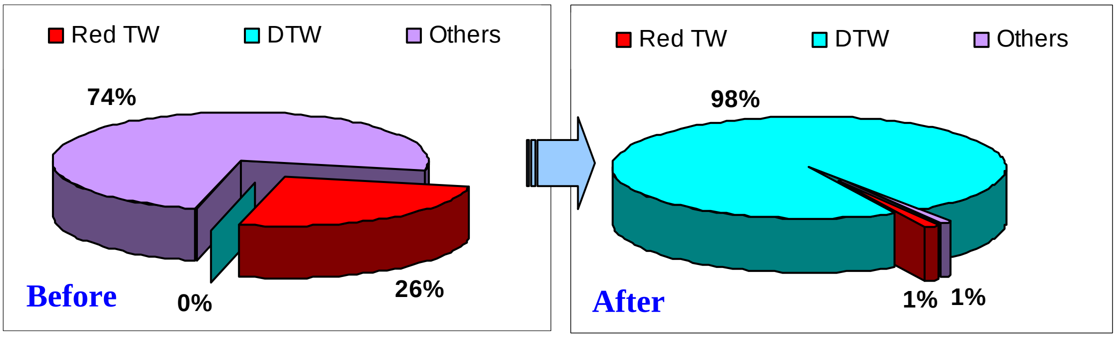


Figure 5.8: Shift in water use pattern before and after installation of DTW

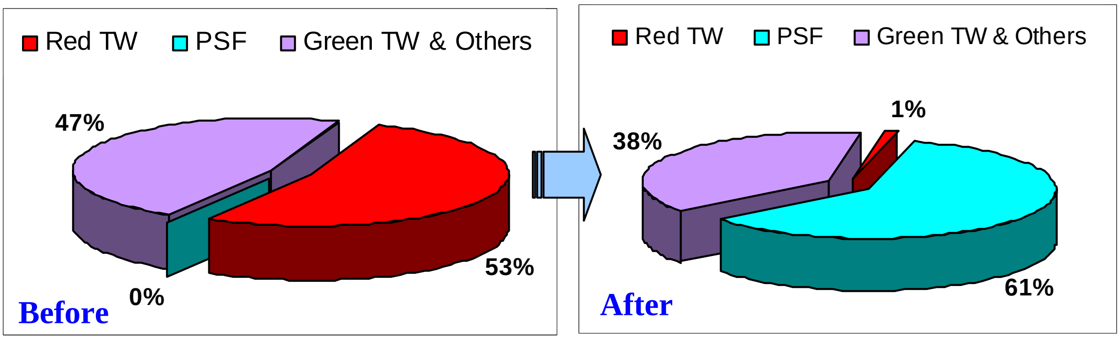


Figure 5.9: Shift in water use pattern before and after installation of PSF

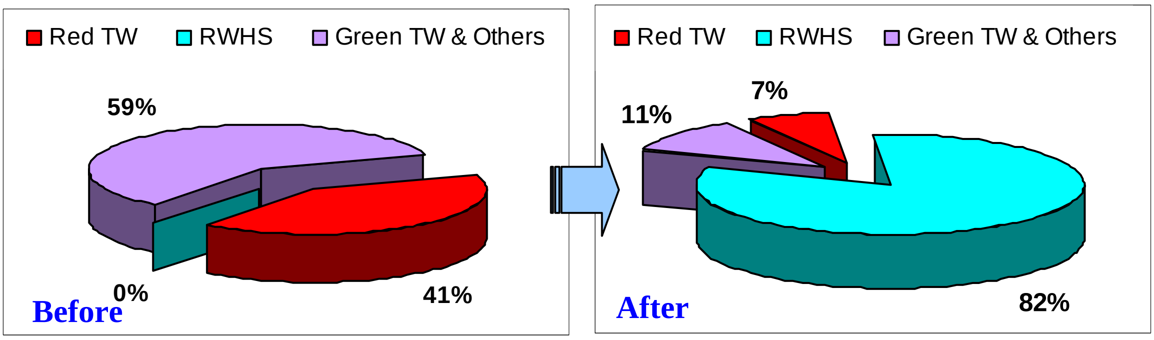


Figure 5.10: Shift in water use pattern before and after installation of RWHS

There is a marked difference in use of the mitigation option for drinking between users of the different technologies, with more DTW users (98%) using the water for drinking compared to RWHS (82%), DW (79%) and PSF (61%). This suggests that some DW and PSF users remain concerned about the quality of the water produced. These findings suggest that users of DTWs and RWHSs appear to have greater confidence in the water they receive than users of DWs and PSFs and that more awareness-raising and education is required in communities receiving DWs and PSFs.

About 40% of the respondent households who now use DWs previously used other sources, 10% used green shallow tubewells at some distance and 50% used red shallow tubewells as sources of cooking and drinking water. Some 17% households used other sources and 4% occasionally use red STW even after installation of DW. The shift in water source for those using DTWs is spectacular, only 2% households used sources other than DTW. Thirty percent of the respondent households who now use PSF's previously used other sources, 17% used green tubewells at some distance and 53% used red tubewells as sources of cooking and drinking water (Figure 5.9). The shift in water source for those using RWHS is also significant. Twenty five percent of the respondent households, who now use RWHS, previously used other sources, 34% green tubewells at some distance and 41% used red tubewells for drinking and cooking. Water from RWHS has a limited use and water is not used for any purpose other than drinking and cooking. This reflects the awareness among RWHS users to conserve stored rainwater especially during dry season.

Water sources other than red shallow tubewells continued to be in use. Pond/river remains a major source of water for cooking, washing and bathing but not for drinking. No DTW users reported using green STWs at some distance after installation of mitigation options compared to 16% DW and 17% PSF users who sometimes fetched water from green STWs. Among RWHS users, about 7% respondents occasionally used water from red tubewells. About 11% respondents either fetch drinking/cooking water from green tubewells at some distance or boil river and pond water for drinking.

This shift in water source is significant as it involves sacrificing convenience of tubewells close to the home for drinking water to a source that is safe from arsenic contamination. Multi-channel campaigns on the adverse health impact of long-term ingestion of arsenic appear to have created a positive impact in this regard.

The purpose for which water from DW, DTW and PSF is used varies with the distance to the mitigation option, as shown in Table 5.4 below.

Table 5.4: Purpose of water use by perceived distance from mitigation option

Purpose Of Water Use	**Distance From Water Source**			**Total**
	Near	Slightly Far	Far	
Drinking only	79	88	33	200
Drinking and cooking	126	64	12	202
Bathing and washing	24	7	1	32
Others	5	2	0	7
All specified	78	22	4	104
Total	312	183	50	545

Households close to the mitigation option use water for a variety of purposes including bathing and washing. The range of uses decreases with the increase in distance to the mitigation. Households that perceive the water point to be far primarily use the water for drinking and cooking and supplement pond or water from tubewell marked red for other purposes.

Among the respondent using arsenic mitigation options, 93% of the respondents started using the DTWs immediately after installation. The corresponding figures for DW, PSF and RWHS are 89%, 87% and 98% respectively. Within six months of the installation of the water points all the respondent households starting using the options. This is not only indicative of the social acceptability of the options but also of the awareness that social mobilization has created on adverse health impact of arsenic ingestion. The general awareness and alternate arsenic safe water points have been instrumental in achieving a shift in water use. Of households who did not start using the mitigation options immediately after installation mention distance as being the primary factor. The DW and PSF users also cite their feeling of uncertainty about the quality of the water as being a reason for non-use of the mitigation option immediately after installation. A CBO member in Bheramara complained that the dug well water was never tested for arsenic after installation and they are not sure about the quality of water they are drinking.

The mitigation options have resulted in a significant reduction in ingestion of arsenic contaminated water in communities where they were installed. The number of respondents using water from red tubewells for drinking and cooking reduced from 144 to 12 after installation of mitigation options. These 12 households occasionally use drink and cook with water from tube wells marked red.

5.2.4 Quantity of water collected

From the interviews with households regarding the volume of water they consume each day, it appears that consumption of water for drinking varies between 3 and 5 litres per capita per day. The average consumption of water from PSF for drinking and cooking varies between 25 and 125 litres per household per day with 88% of the respondent households using an average around 25 litres daily. The estimate of number of litres of water per household per day from RWHS is also similar to that for PSF.

A study by NGO Forum in rural Bangladesh indicated that the daily drinking water used by rural households varies between 20 and 27 litres per day. Considering an average household size of a little over 5 in rural Bangladesh the per capita consumption from the NGO Forum study is consistent with the figure derived from the discussions with households in this assessment.

5.2.5 Attitudes of users to arsenic mitigation options

Respondents were asked for their views on the mitigation option and whether they consider it to be a permanent solution to arsenic problem. The users perception about the DW, DTW, as permanent solution to the problem are presented in Figures 5.11 and 5.12 respectively.

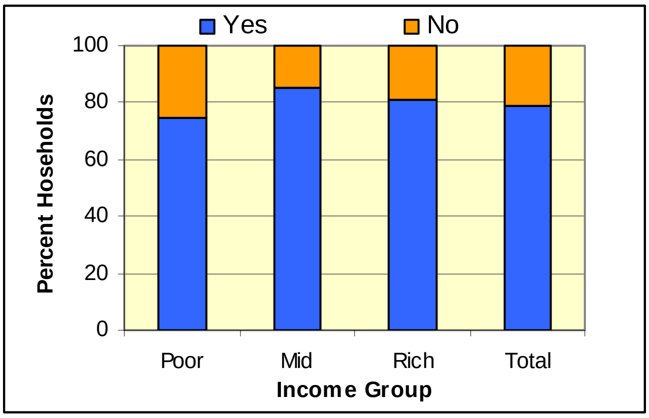


Figure 5. 11 : Users' perception about DW as a permanent solution .

Over 87% of all respondents considered the option provided to be a permanent solution to the arsenic problem. This was higher for users of DTWs (96%) compared to users of DWs (79%). It is interesting to note that for both options, the proportion of poor families that consider the option to be a permanent solution is lower than for middle-class and rich families (75% for DWs and 94% for DTWs). This suggests that poor families have an aspiration for a better water supply, which would agree with studies undertaken by WSP and BRAC (WSP, 2003).

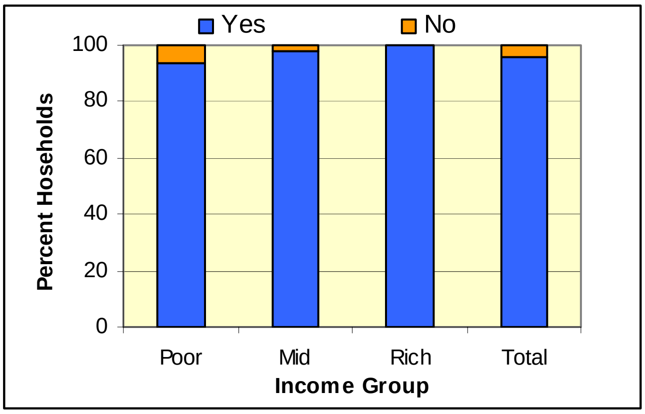


Figure 5.12 : Users' perception about DTW as a permanent solution .

It may be that because middle-class and rich families still have access to a tubewell close to their home that they can use for purposes other than drinking and cooking, they have little demand for improvements beyond provision of an arsenic-safe water source for drinking and cooking. By contrast, poor families may have access only to mitigation options and therefore desire access to other sources for hygiene and other purposes. The users generally believe that both DW and DTW will finally provide arsenic-safe water but users' confidence on DTW is comparatively higher. However, the attitudes of the people are the result of large-scale motivation in arsenic affected areas.

Similarly, the attitude of the users about PSF and RWHS are presented in Figure 5.13 and 5.14 respectively. An overwhelming majority of 95% of the respondents see PSF as a permanent solution to the problem of arsenic contamination. Within each income group, over 90% of households see PSF as a permanent solution, with almost 98% of poor households considering a PSF to be a permanent solution to arsenic contamination.

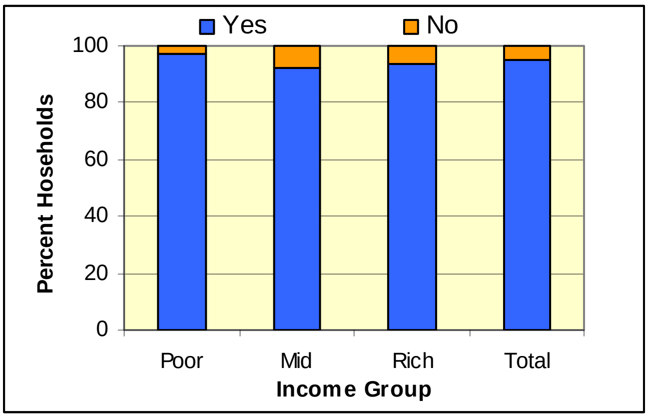


Figure 5.13: Users' perception about PSF as a permanent solution .

About 59% of the RWHS users think that the option could be a permanent solution to the problem of arsenic. However, 40% do not think RWHS can provide a permanent solution. Very few poor households have RWHS and only 12% of poor households viewed RWHS as a permanent solution. Middle class and rich households generally appear to consider RWHS as a permanent solution. However, RWHS is acceptable as temporary measure in the absence of a permanent solution or to supplements other systems. Thirty of the 52 respondents in the DPHE/UNICEF/IDE RWH study would prefer "permanent" options other than RWHS.

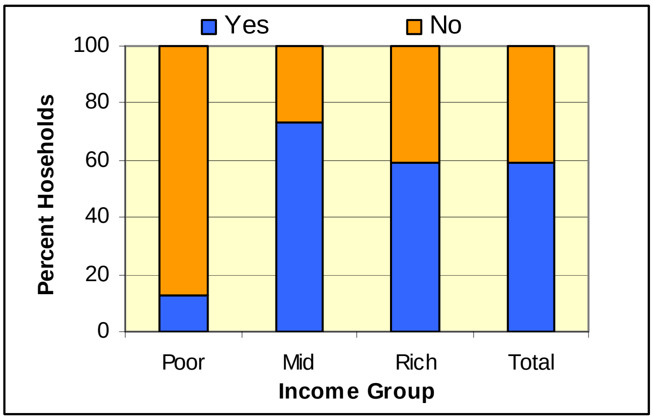


Figure 5.14: Users' perception about RWHS as a permanent solution .

Under the prevailing socio-economic circumstances, poor households are likely to see community mitigation options as their only way of accessing arsenic safe water for drinking and cooking. A report from the UN Foundation Project (UNICEF & WHO, 2003) confirms this contention. The poor on the other hand do not own RWHS and so have limited incentive to favour RWHS over PSF. More rich and middle-income families also appear to consider PSF a permanent solution than RWHS. Despite greater ability to afford a RWHS, these groups do not necessarily favour this over a communal solution.

It would appear that in general, most respondents view the mitigation options being provided as acceptable in terms of quality and as a permanent solution. In this study, there were no reports of rich or influential people denying the poor access to water from mitigation options, although this has been found in other studies (Hanchett, 2004).

5.2.6 Satisfaction of the users

The satisfaction with respect to the quality of water supplied by DW and DTW was investigated and the results are shown in Table 5.5.

Table 5.5: User satisfaction with water quality of mitigation option by income status

Family Income Status	**Dug Well No. HH (%)**			**Deep Tubewell, No. HH (%)**			**Pond Sand Filter, No. HH (%)**		
	Satisfied	Not satisfied	Total	Satisfied	Not satisfied	Total	Satisfied	Not satisfied	Total
Poor	90(86)	15(14)	105	95(92)	8(8)	103	91(95)	5(5)	96
Middle	37(90)	4(10)	41	58(91)	6(9)	64	61(92)	5(8)	66
Rich	28(88)	4(12)	32	12(100)	0(0)	12	29(88)	4(12)	33
Total	**155**	**23**	**178**	**165**	**14**	**179**	**182**	**13**	**195**

The respondents using DW, DTW and PSF mostly stated that they were satisfied with the quality of water from the mitigation options. There was little difference across the income status groups regarding the level of satisfaction with the water quality, but a greater proportion of users of PSF (93%) and DTW (92%) were satisfied with the quality of water than users of DWs (87%). The overall proportions of users satisfied and not satisfied with DW, DTW and PSF and the proportion of unsatisfied users by each of the three options are shown in Figure 5.15. The unsatisfied households are users of DW (47%) compared to DTW (28%) and PSF (25%).

Of the poor who use DWs 86% are satisfied with water quality compared to 92% of the poor using DTWs and 95% using PSF. There is overall good satisfaction with the functioning of the mitigation options with 89% of the respondents using DTW being satisfied and 82% of users of DWs. Almost all RWHS user respondents are satisfied with the quality of water. The large majority of respondents using the options are satisfied with the performance of the options.

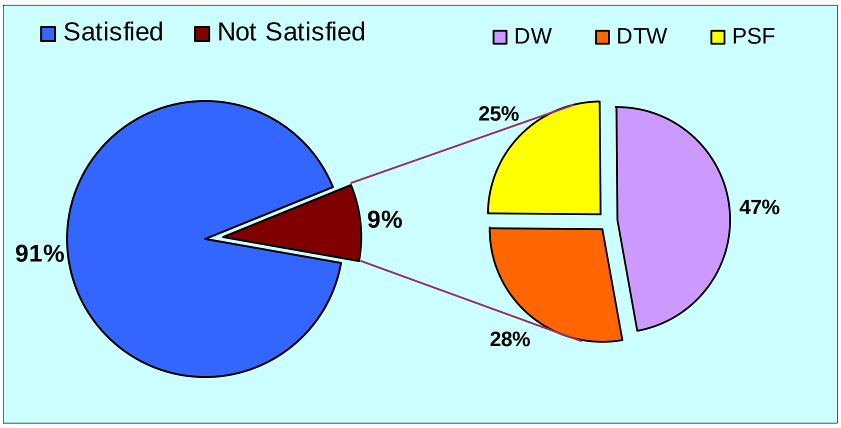


Figure 5.15 : Users' satisfaction with quality of water of DW, DTW and PSF

DWs have been a traditional and socially acceptable water source in the sample Upazilas where DWs were provided as a mitigation option. With extensive proliferation of hand tubewells, DWs were gradually giving way to STWs but had not totally gone out of fashion. Some households claimed to have been using DWs for drinking and cooking before the installation of a new or rehabilitation of an old DW as mitigation option. As rehabilitation of old DWs costs less than installing new DWs, arsenic mitigation programme could take advantage of this and where possible give priority to DW rehabilitation and upgrading, rather than new DW construction.

The traditional use of DWs is likely to be important in determining whether they will be viewed as an acceptable solution to arsenic mitigation. In areas where DWs were traditionally used, they will find ready acceptance in areas as an arsenic mitigation option. In areas where DWs have not been traditionally used, they may be less acceptable to communities. For instance, a rapid assessment of BAMWSP activities in Hajiganj, shows that the population did not like DWs (UPI, 2002). There is no evidence to show that DWs had been a traditional source of water in Hajiganj prior to the advent of tubewells and this may be due to problems with water quality. Hajiganj is a low-lying area and the top layer of the soil is replete with putrescent plant waste that gives water at very shallow depths a putrid smell. Furthermore "sand-boiling" rapidly fills up DWs casting doubts on technically feasibility of DWs in Hajiganj.

5.2.7 Operation and maintenance

All the water points surveyed have been installed within the last two years. None of them were in need of any major repair. The number of respondents aware of operation and maintenance responsibility was investigated. Overall, 87% of the respondents knew of caretakers to look after the water points, but 32% of those who knew of caretakers were not very sure of who selected or who trained them. Responses varied from selection by Union Parishad chairmen to project and user community.

The repairs of water points in the last six months comprised minor work such as changing buckets, nuts or bolts. No respondent in formal or informal conversation mentioned chlorination, as an essential part of DW maintenance. This goes to confirm DASCOH's finding that 80% of the DW users are not chlorinating the DWs regularly (DASCOH, 2004). The repairs of PSFs in the last six months comprised minor work such as changing buckets, nuts or bolts of the hand pumps and cleaning of filters. The real test of effective operation and maintenance of PSF's will be when the filter needs a complete overhauling. That is yet to come as no respondent has yet reported it. Ninety nine percent of the respondents asserted that the PSF has been working well without any major problems. Operation and maintenance of RWHS comprised cleaning of roofs, storage tanks and gutters. Twenty eight percent of the respondents using RWHS claimed that minor maintenance was necessary.

Sixty percent of the respondents knew of caretakers to look after the PSF, but 15% of those who knew of caretakers were not very sure of who selected or who trained them. Response from those who knew of caretakers varied from selection by project sponsors, Union Parishad chairmen to user community. Twenty three percent of respondents did not know who performed the maintenance. In the absence of caretakers, the owners of the pond or household nearest to the PSF's undertake the operation and maintenance. The maintenance of RWHS is primarily the responsibility of the household using the system.

The respondents were rather confused in responses to the questions on training. Courtyard sessions for awareness building on arsenic or orientation on technology options were often mistakenly reported as training sessions. This is understandable as only caretakers who received training would be in a position to respond to such questions. Caretakers did receive training and respondents who were also caretakers could mention duration and content of training.

5.2.8 User groups and community based organisations

Where user groups or community based organisations (CBOs) were reported to have been formed for DW and DTWs, the study found that only 9% of the respondents knew of their presence but were not sure as to when they were formed, who the members were and what purpose they served. An example of this comes from Bheramara, where support organizations appointed by BAMWSP formed CBOs, trained them and got them to prepare community action plans. However, respondents interviewed and discussions with other community members found that most people expressed their ignorance about the CBOs. Even a Union Parishad Chairman elected in February 2003 was unaware of the CBOs.

A member of one such CBO in Bheramara did not see much use of the CBO as it did not involve the full community and was limited to a selected few. Most of these CBOs were never very active. This leads to limited effectiveness of the CBOs. For instance, a member of a CBO claimed that the Union Parishad Chairman does not even share the information on financial transactions with the CBO members. In the same Union, a DW installed through CBO still remains incomplete but the bill for the construction has reportedly been settled.

In cases where PSF user groups or community based organizations (CBO's) were reported to have been formed, 34% of the respondents knew of their presence and 30% believed that they are still working, effective and useful in managing the PSF's. CBO's however, were not a necessity for the RWHS and were not formed. No respondent, except those who had volunteered ponds for PSF's were found to be directly involved in decision making. Only 43% of the respondents claimed to have directly participated in selection of PSF's. About

74% has not contributed anything towards the cost of construction. RWHS being a household option needs only the participation of the household rather than the community.

It should be noted, however, that the findings presented here on CBOs primarily come from an area served by only one programme, BAMWSP, and comparable discussions were not held with communities that had received arsenic mitigation options from other programmes (such as DPHE-Danida or DPHE-Unicef). It is therefore possible that more positive experiences are available from these other programmes.

The process of user group or CBO formation is as important as the group itself. User groups or CBOs formed to satisfy project requirement without a participatory process of consultation and consensus building tend to be short-lived. These groups will not be able to galvanise people to action in times of need. The CBOs formed under BAMWSP in Bheramara are inactive, casting doubts on the adequacy of the process or the competence of support organizations (SOs), who conducted the process or both. A rapid assessment of BAMWSP activities at the local level by the Unit for Policy Implementation in 2002 draws a similar conclusion.

The assessment indicates that the process of user group or CBO formation has not been very participatory and may in future affect sustainability of the options. The current process of CBO formation is not resulting in an effective mechanism for operation and maintenance of the mitigation options. The sanitary inspection data reported in section 4.5 indicates that operation and maintenance is already beginning to deteriorate and this may become a greater problem in the future with ineffective CBOs and lack of participation.

In planning and implementation of the mitigation options broad-based participation appears to have been largely absent and some respondents interpreted contribution for the water point as participation. No respondent, except those who had given land to install the facilities were found to be directly involved in decision making on the water points.

5.2.9 Awareness of arsenic

Data were collected on awareness of arsenic and when they had first become aware of arsenic as a problem in their water supplies. As shown in Figure 5.16, the majority of respondents (70%) had first been informed about arsenic more than two years ago and 16 % having heard of arsenic in the last two years and 12% in last one year. The remaining could not recollect when they first heard of arsenic or did not respond.

About 84% of the cases NGOs, word of mouth and radio/television were the main sources of information on arsenic as shown in Figure 5.17. Word of mouth with 37 % takes the lead followed by radio/television at 26 %. This is no surprise as 72% of the respondents were women who seldom venture out of homes.

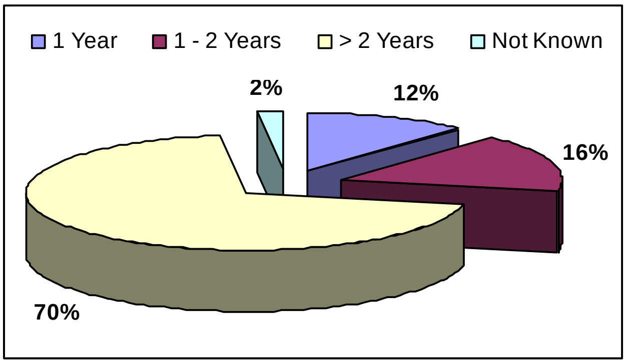


Figure 5. 16: When the respondents first knew about arsenic contamination

Only 63% of the respondents knew that the DW and DTW were installed because of arsenic contamination of existing tubewells and others thought it was just another water point to provide water to people. A little more than 72% of the respondents knew that the PSF was installed because of arsenic contamination of existing tubewells and 93% RWHS users knew that arsenic was the main reason for installation of the RWHS. Considered against the backdrop of absence of broad-based participation in planning and installation of the water points, the proportion of respondents who knew of the reason for installing PSF is high. This is a credit to the awareness campaigns the government and NGOs launched.

The above is in variance with a high proportion of respondents considering the mitigation options as a permanent solution to arsenic contamination. The reason for this may perhaps lie in the framing of the questions. The question on reason for installing the option had four possible answers but the one on whether or not the option is a permanent solution had only two possible responses. The probability of any two respondents giving the same answer to a question is inversely proportional to the number of possible responses. Thus had fewer response been available for the reason for installing an arsenic mitigation option, the proportion of people stating the option was installed because of arsenic would be expected to e higher.

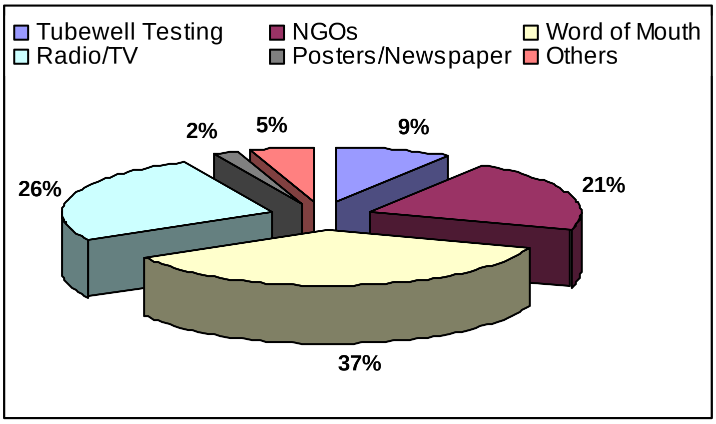


Figure 5.17: How the respondents learned about arsenic contamination

The majority of respondents knew that arsenic contaminated water from tube wells marked red should not be used for drinking and cooking, but 79% did not know that arsenic contaminated water may be used for other purposes. This has implications for both awareness campaigns and water use. People not using water from tube well marked red for purposes other than dinking and cooking means lost investment and worse still may drive people to use polluted pond and river water.

Of the total users of alternative water supply, 53 % knew that arsenic is a poison that gradually affects health and 44% respondents could identify at least one physical symptom of arsenicosis. The perception that arsenic is a poison that affects health is about three times higher among households using DWs than those using DTWs. Perhaps the longer time needed for installation of DW than to DTW has resulted in greater awareness among DW users. There is no significant difference in perception among users of PSF's and RWHS's. Only about 3% of the respondents knew that arsenic is not contagious.

However, this is in contrast to the findings that respondents using red tubewells after installation of the PSF's and RWHS's do so for purposes other than drinking and cooking. It may be explained by the fact that people in Bangladesh recognise the importance of drinking safe water but continue to use polluted sources for other uses. The respondents are just prioritizing safe water for drinking and cooking over other uses.

5.3 Recommendations

The high proportion of user satisfaction with DW, DTW, PSFs and RWHs proves beyond doubt the social acceptability of all the options deployed for arsenic mitigation. The highest proportion of people expressed their satisfaction over installation of DTW and finds it as a permanent solution to the problem of arsenic contamination. From the social perspective there is no concern in promoting DW, DTW, PSFs and RWHSs as mitigation options in arsenic affected areas. Available papers and reports also confirm the social acceptability of the options.

The acceptance of RWHS across a wider income spectrum at full cost would require promotion of a range of RWHS models. The models could range from simple guttering with storage in "motkas and kolshis" and "do-it-yourself systems" to up-market solutions with elaborate guttering and a choice of storage tanks. Credit and payment in installments may help more households acquire RWHS.

Future arsenic mitigation programmes that deliver community facilities must improve on community mobilisation and building awareness on use of water from red tubewells for purposes other than drinking and cooking; and that arsenicosis in not contagious. Awareness campaigns on arsenic and its ill affects should bear in mind that the best means of spreading messages are the radio and television, NGOs and word of mouth.

Mitigation programmes tend to leave out the poor and the disadvantaged from planning and decision making process. The poor particularly have a higher stake as they are unable to own individual mitigation options and are likely to have a higher commitment to operation and maintenance of community facilities. Mitigation programmes should widen participation to include users of all income categories and gender. Participation is required not only in planning, implementation and operation and maintenance of mitigations options but also in sharing of information on different aspects of arsenic and available technology options.

Community-based facilities more often fail due to inadequate operation and maintenance. Operation and maintenance may prove to be a problem when the burden of overhauling the filter arises of PSF. Future programmes would do well to commit skill and resources to develop local user-based mechanism for effective management and operation and maintenance of community mitigation facilities or alternate sources of drinking/cooking water.

6

DISEASE BURDEN

6.1 Introduction

A key component of the RAAMO project was the estimation of disease burden of the arsenic mitigation options through development of a suitable tool. The purpose of estimating the disease burden was to support technology choice selection in arsenic mitigation to help reduce disease burdens attributable to arsenic without creating even greater disease burdens attributable to microbial pathogens. The potential for risk substitution in arsenic mitigation is significant, particularly as technologies that are less robust with respect to control of microbial quality. The tool was developed to provide a means of fulfilling the recommendations of the conceptual framework proposed by WHO (Howard 2003).

In water supply options analysis the financial, technical, health, environmental and social feasibility of each option are considered. In relation to health, the technology option presenting the lowest disease burden would always be preferred from the choice available given the constraints placed on that choice. Where the presence of the same hazard (contaminant) is being compared, the choice is simple: the water supply option with the lowest probable concentration of that hazard should be chosen. However, where different types of hazards are being compared simultaneously the choice is more complex.

6.2 Quantitative health risk assessment

The use of quantitative risk health assessment (QHRA) is an emerging tool to support decision-making in developing countries. The benefit of quantitative risk assessment is that it allows comparisons to be made among different technologies based on often relatively easily acquired input data. The best available expertise and evidence are assembled to make best supportable risk estimates. As new understanding emerges, predictions are revised. However, quantitative risk assessment does not replace epidemiology and the two approaches to health assessment are complementary.

In the present study, a QHRA model that can support adaptive risk assessment and risk management was developed and applied to support a water supply options analysis. The generic quantitative risk assessment paradigm (WHO 1999, WHO and FAO 2003) was adopted in structuring the QHRA. This is summarised as follows:

- Problem Formulation;
- Hazard Identification;

- Exposure Assessment;
- Dose-response Assessment; and
- Risk Characterisation.

In the RAAMO disease estimation tool, the 'problem formulation' was defined as "*Which arsenic mitigation option presents the lowest disease burden in a particular setting?*" To the extent that assumptions were supported, the model assists in evidence-based decision making. Where the assumptions were not well supported, the model assists in hypothesis generation and research priority identification.

6.2.1 Modelling approach

The WHO recommends the use of QHRA as part of the assessment of water supply options and to inform risk assessment and management (WHO 2004, Deere *et al*. 2001). The need for high-cost proprietary software and experience in mathematical modelling has historically limited the use of probabilistic QHRA to developed-world applications. However, Howard *et al.* (2005) recently demonstrated that a deterministic risk assessment model can be usefully applied in developing countries with available data and information as part of the implementation of the WHO Water Safety Framework (WHO 2004).

In the present study a deterministic model was developed that could be run in any generally available spreadsheet package, making it generally applicable to developing-world applications. The architecture of the model as used is given in Figure 6.1 and shows that readily available thermotolerant coliform (TTC) and arsenic concentration data are the only required model inputs. Two additional innovations were applied in building from the Howard *et al*. (2005) work as follows.

Firstly, to enable limited uncertainty analysis, the Slob (1994) uncertainty analysis methodology was built into the deterministic model, which is valuable, although it should be noted that this has limited the frequency distributions that could be applied within the model to being either normal or lognormal. Outputs were expressed as the median as well as the upper and lower limits of the 90% confidence interval. Therefore, within the model, parameters were expressed either as a single point value if there was no basis to include an uncertainty estimate or, if there was a basis to derive an uncertainty estimate, as two values (mean and standard deviation of the lognormal distribution).

Secondly, both microbial and arsenic risks were combined in the same model enabling microbial and chemical risks to be balanced in assessing the health impacts of arsenic mitigation options. An important and challenging consequence of balancing risks in this way is that applying blatantly conservative assumptions will lead to biases that would prevent a fair assessment. Therefore, "best supported" or "most reasonable" assumptions must be used.

The use of quantitative health risk assessment for different types of hazards requires that a measure is used that can capture and compare the different outcomes of arsenic and pathogens. The most commonly used metric is the Disability Adjusted Life Years (DALYs) approach, which combines assessment of morbidity (illness) and mortality (death) and allows different diseases and illness to be compared (Murray and Lopez, 1996). DALYs were used in this study in line with recommendations from the World Health Organization (Havelaar and Melse 2003; WHO 2004).

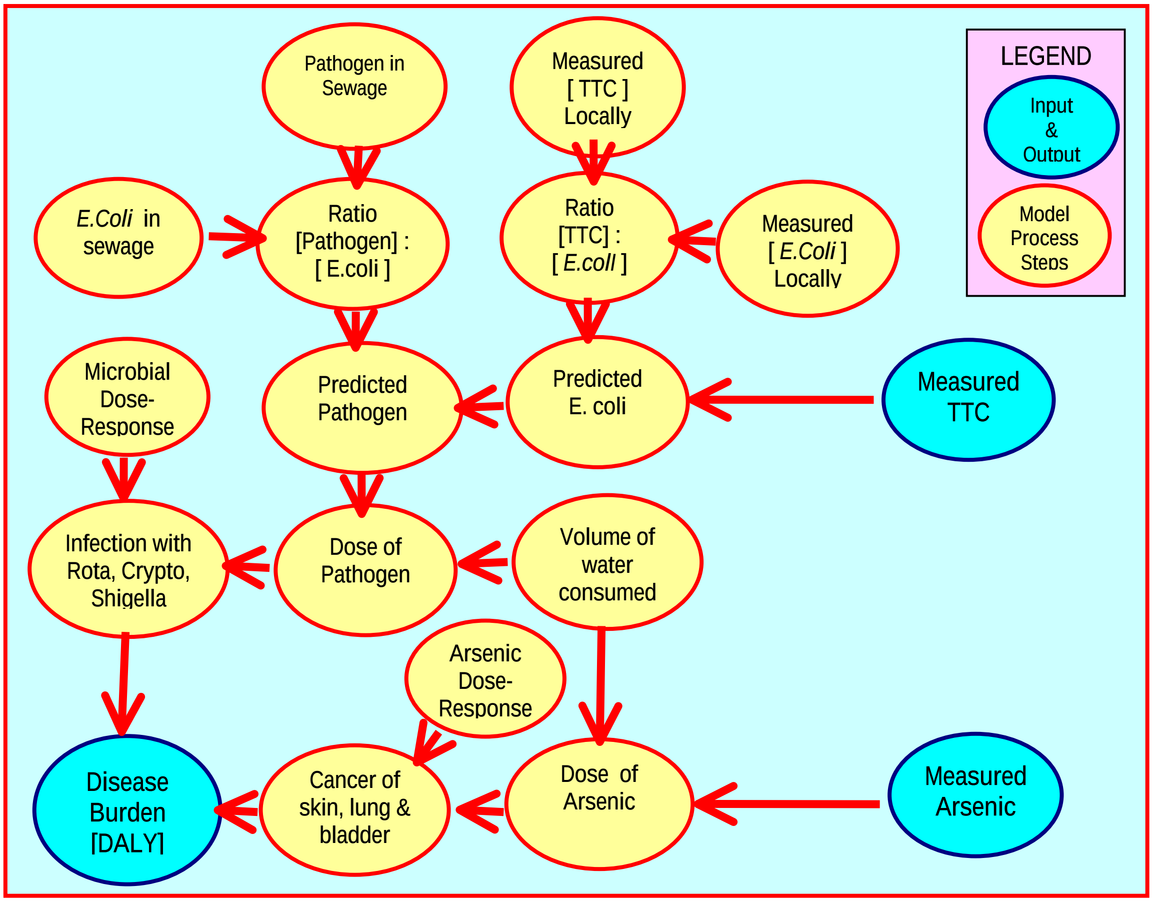


Figure 6.1: Overview of Model architecture

6.2.2 Hazard analysis

The hazards of interest in this analysis were microbial enteric pathogens and arsenic. WHO (2004) promote the "reference pathogen" concept in which the most resistant, abundant, infectious and virulent pathogens are used for risk assessment and for risk management planning. The basis for accepting the use of reference pathogens arises from the fact that not all of about 150 waterborne pathogens can be modelled due to lack of data but that reference pathogens, which can be one "worst case" specific pathogen or a "model" pathogen, will represent most of the risk.

In accepting this concept, model reference protozoan, bacterial and viral pathogens were defined for this study. A summary of the properties of these model reference pathogens is given in Table 6.1 with full details being given in section 6.2.

Table 6.1: Summary of properties of the model reference pathogens (details are given in material and methods)

Model reference pathogen	Basis for concentration estimate	Basis for infectivity estimate	Basis for disease burden estimate
Virus	Total cultivable enteroviruses from sewage relative to *E. coli*	Human feeding trial of rotavirus	WHO generalised developing-world rotavirus
Bacterium	Total cultivable *Salmonella* spp from sewage relative to *E. coli*	Human feeding trial of *Shigella dysenteriae*	WHO generalised *E. coli* O157:H7
Protozoan	Total confirmed *Cryptosporidium* oocysts from sewage relative to *E. coli*	Human feeding trial for *C. parvum*	WHO generalised *C. parvum*

6.2.3 Model inputs

Ideally, the analysis of a suite of pathogenic, indicator and index organisms would be analysed in assessing microbial water quality as an input to health risk assessment. However, in reality, risk assessments in developing countries will need to make use of thermotolerant coliforms (TTC) as the principal microbiological input. This is because cost and skill levels generally preclude the use of *E. coli* tests in developing countries for community-managed water supply analysis. The field kits generally used do not test for *E. coli*, but for TTC. Furthermore, analysts are generally not professional microbiologists but are trained water and sanitation workers, able to use the field kits but not skilled at microbial typing and pathogen monitoring.

The TTC values used as the inputs to the model were obtained from the field studies, with some confirmatory testing for *E. coli*. The results show that *E. coli* were often present and that the TTC isolates were likely to be heavily faecal-derived. However, the data were not sufficient to enable a ratio of environmental : faecal TTC to be confidently defined.

6.3 Model components

6.3.1 Arsenic and TTC model inputs

Arsenic concentrations [As] and TTC concentrations [TTC] were used as inputs to the QHRA model for five different technologies in two seasons (dry and monsoon). To provide the numerical values, the data for each condition (technology and season) were fitted to lognormal distributions using maximum likelihood iteration and then checked by visual examination of the fit (Figure 6.2). The mean and standard deviation of the lognormal distribution that best fit the observed data provided the numerical model input.

The [As] was applied directly as an input to the dose-response relationship. The [TTC] was used as a basis for predicting pathogen concentrations ([pathogen]) since pathogen concentrations were not measured directly. The important difference between the two approaches used for arsenic and pathogens is based on the difference in the basic epidemiology from which the dose-response model is derived. For arsenic, the dose response relationship is based on relevant [As] measurements (dose) and disease prevalence in the community (response). In contrast, for pathogens, the dose response relationship is based on human feeding trials of known doses of pathogens (dose) and measured health effects of those consuming the pathogens (response). Therefore, an important requirement for the microbial component of the model is to predict [pathogen] against given [TTC].

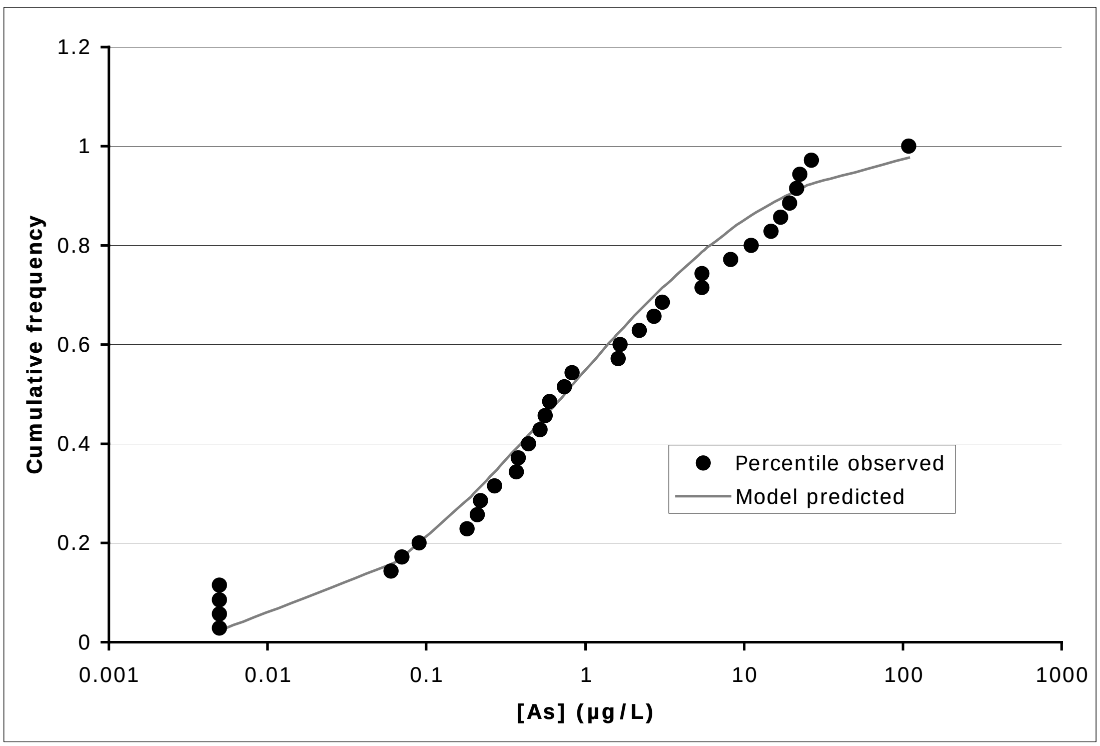


Figure 6.2. Examples of the fitting of observed data to a best-fitting lognormal distribution

6.3.2 Sanitary significance of thermotolerant coliforms (TTCs)

Assumptions were made regarding the proportion of TTC that were likely to be of environmental origin, the remainder being assumed to be of faecal origin. The proportion of TTC that were assumed to be of faecal origin were assumed to be *E. coli* for the purpose of predicting pathogen concentrations. A lognormal distribution was used to represent the proportion TTC that were of environmental origin and had a mean of 15%

(so that 85% were assumed to be of faecal origin and were assumed to be *E. coli*) with a standard deviation leading to an lower and upper 90% confidence limit of 7.5% and 30% respectively (illustrated in Figure 6.3).

The reason the percentage of TTC assumed to be of environmental origin is expressed, rather than the reverse (the percentage of TTC that are assumed to be of faecal origin) is because the former was thought to provide a more natural fit to the left-shifted skew of the lognormal distribution.

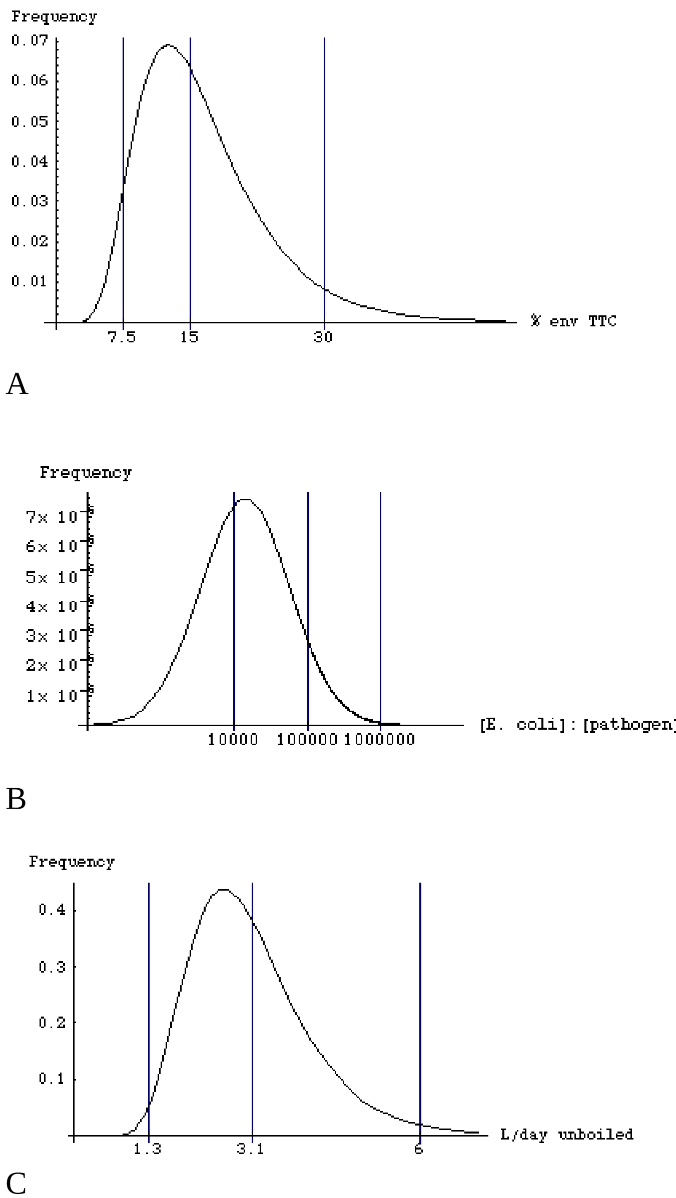


Figure 6.3: Examples of frequency distributions applied in the model [(A) Proportion of TTC that are of environmental origin with vertical bars illustrating the median and 5th and 95th percentile values. (B) Log-linear plot of the ratio of [*E. coli*]:[pathogen] for viral and bacterial pathogens with vertical bars

illustrating the median, 5^{th} and 95^{th} percentile values. (C) Volume of water consumed unboiled with vertical bars illustrating the mean, minimum and maximum values given in Watanabe *et al.* (2004)].

6.3.3 Ratio of E.coli and Pathogen ([E. coli]:[pathogen])

Pathogen and *E. coli* monitoring in raw sewage provides an indication of the ratio of pathogens to *E. coli* that might be expected in human faecal matter deposited on land, in water and in latrines. Therefore, in predicting [pathogen] based on [*E. coli*] the ratio of [*E. coli*]:[pathogen] in reports of sewage quality monitoring were assessed. Such an approach has previously used to support the assessment of risks to recreational water users (Craig *et al*. 2003). The studies reviewed and the ratios applied are given in Table 6.2 from which the most recent studies with the largest and most reliable datasets were selected to provide the primary basis of the ratios applied.

The pathogen concentration may be higher in Bangladesh than in the cited developed-world studies although this assumption is tentative and is based on the following observation. Stool specimens from 1 in 50 hospitalised patients in a hospital in Dhaka (regardless of presentation) were analysed to test for the presence of a limited number of important pathogens (ICDDR,B, 2003). Results indicate that approximately 10% of samples are positive for rotavirus and a similar proportion are positive for *Shigella*. In contrast, pathogen prevalence in stools from an 18-month (1997 to 1999) prospective epidemiological study in Melbourne, Australia, found rotavirus in only 1.4% of faecal samples submitted from 791 study subjects reporting gastroenteritis (although only three were hospitalised, the study was following subjects at home) and did not isolate any *Shigella* (Hellard *et al*., 2001). The Melbourne study design was such that the results can be considered to be reasonably representative of a population in a developed-country city, but may not be reliable with regard to rural Bangladesh.

It is possible that the [*E. coli*]:[pathogen] ratio in water in Bangladesh is lower than applied and current data are being sought to attempt to test and define this assumption. In the interim, the studies with the lower ratios have been considered more applicable to the current study, summarised in Table 6.2.

The values used within the model for the [*E. coli*]:[pathogen] ratios were defined with a dispersion factor whereby the 90% confidence interval spanned two $\log_{10}$. This level of dispersion was introduced into the model to take account of two primary sources of variation and uncertainty.

Human faecal matter might be deposited on land and in latrines from where it might contaminate water sources by leaching or by surface water overflow and infiltration. Surface flow, and even more so subsurface flow, could lead to a rise in the [*E.coli*]:[protozoan] ratio that could conceivably increase by an order of magnitude at the same time as leading to a drop in the [*E.coli*]:[virus] ratio that could conceivably decrease by around one order magnitude due to the differential motilities of viruses, protozoa and bacteria (Ferguson *et al*. submitted).

Animal faecal matter is likely to be present and available to contaminate water sources since most rural Bangladeshi households have at least one stock animal - 45% have a cow, bull or ox, 26% have a goat or sheep and 77% have poultry (Caldwell *et al*. 2003). The mammals will carry human-infectious strains of protozoan pathogens and both birds and mammals will carry human-infectious strains of bacterial pathogens (WHO 2004). However, neither are established sources of waterborne human-infectious enteric viruses (WHO 2004).

Table 6.2: Data used to estimate [*E. coli*]:[pathogen] ratios in sewage

	Ratio [*E. coli*]:[Pathogen]		
Study	**Virus (enterovirus)**	**Bacteria (*Salmonella* spp)**	**Protozoa (*Cryptosporidium*)**
USA, raw sewage (Rose *et al* 1996)[1]	2.2×10^7	NR	1.5×10^7
Netherlands, raw sewage (Lodder and de Roda Husman in press)[2]	1.4×10^6	NR	NR
Scotland, raw sewage (Robertson *et al* 1999) [2]	NR	NR	6.3×10^6
England, raw sewage (Robertson *et al* 1999) [2]	NR	NR	1.9×10^6
Scotland, raw sewage (Robertson *et al* 2000) [2]	NR	NR	4.0×10^6
New Zealand raw sewage (Simpson *et al* 2003) [2]	2.6×10^5	NR	NR
Brazil, raw sewage (Lopez-Pila and Szekzyk 2000 citing Mehnert and Stewien 1993)[3]	1.8×10^5	NR	NR
Australia, raw sewage (unpublished, Cunliffe, D. pers. comm.) [2]	NR	NR	*1.4×10^6
Australia, raw sewage (unpublished, Stevens, M. pers. comm.)[4]	5.9×10^4	3.8×10^5	5.7×10^6
Australia, raw sewage (unpublished, Stevens, M. pers. comm.) [4]	*1.1×10^5	*1.5×10^5	6.2×10^6
Average	4.8×10^6	2.6×10^5	5.7×10^6
Median, (and lognormal 5th percentile and 95th percentile) values used in model[6]	10^5 (10^4, 10^6)	10^5 (10^4, 10^6)	10^6 (10^5, 10^7)

NR: Not reported
* studies considered the most reliable based on the size of dataset, their currency and the level of experience of the laboratory employed
[1]comparison with reported [TTC] no reported [*E. coli*]
[2][*E. coli*] not reported, compared with the average of the [*E. coli*] from the two Melbourne and the [TTC] from the US studies
[3]comparison with rotavirus not enterovirus; pathogen recovery efficiency was considered to be likely to be poor

[4]*Salmonella* spp most probable number (MPN) in secondary treated effluent compared with *E. coli* in that effluent. Assay results were all positive in raw sewage making MPN determination impossible
[6]based on the observed medians from the three studies indicated by "*" which were considered the most reliable based on the size of their datasets, currency and laboratory used.

The mass of faecal matter produced by domestic animals is large, with, for example, 27.25 kg and 1 kg manure per day per cow and sheep respectively being reported (Olley and Deere 2003). Even assuming 6 persons per household (Caldwell *et al.* 2003) each producing a few hundred grams of faeces per day, domestic animals are likely to produce around one order of magnitude more faecal material than the amount produced by the human population and only the latter will use latrines. Furthermore, domestic animals, particularly juveniles, are known to have very high prevalence rates of protozoan pathogens, often reaching 100%, even in developed countries (Olley and Deere, 2003; Cox *et al* submitted). The effect of the presence of so much animal manure would be to drop the [*E. coli*]:[protozoan], conceivably by an order of magnitude, and raise the [*E. coli*]:[virus] ratio, conceivably increase by an order of magnitude.

For the QHRA model, the [*E. coli*]:[pathogen] ratios for the virus, bacterial and protozoan model reference pathogens were described by lognormal distributions with means of 10^5, 10^5 and 10^6 respectively and the lower and upper limits of the 90% confidence interval being 10^4, 10^4 and 10^5 and 10^6, 10^6 and 10^7 respectively.

The reason the [*E. coli*]:[pathogen] ratio is expressed rather than the reverse, (the [pathogen]: [*E. coli*] ratio) is because the former was thought to provide a more natural fit to the left-shifted skew of the lognormal distribution.

6.3.4 Volume of unboiled water consumed

Single-hit theory dose-response models applied for pathogens use the product of pathogen concentration and volume of water consumed to give the dose (Haas *et al*. 1999). Since the boiling process applied in cooking inactivates pathogens, the pathogen dose was calculated with reference to the volume of unboiled water consumed.

Watanabe *et al*. (2004) analysed water consumption in two rural Bangladeshi communities. An average of 3.1 l/day (n = 38, range 1.3 to 6, average standard deviation of 1.0) of water was directly consumed. Based on an analysis of variance there was no significant difference between males and females nor between the two communities, at the 95% confidence level. The Watanabe *et al*. (2004) findings were reasonably consistent with those of Milton *et al*. (2004) who estimated a mean direct water consumption of 3.53 l/day (standard deviation 0.98).

Based on these observations, the volume of unboiled water consumed was represented within the QHRA model by a lognormal distribution with a mean of 2.9 l/day and 1.3 and 6 l/day being the 1st and 99th percentiles (being the lowest and highest values reported by Watanabe *et al* 2004) respectively. It was assumed that all water said to be directly consumed in the Watanabe *et al* (2004) study was unboiled as there were no indications to the contrary in the report, although this was not explicitly stated.

6.3.5 Arsenic dose-response

A broad range of disease endpoints have been attributed to excessive arsenic consumption. The most recent broad review proposed that the strongest evidence related to cancers of the skin, lung and bladder and to cutaneous effects such as pigmentation changes and hyperkeratosis (Brown and Ross 2002). For the purpose of the present study, only these most strongly supported endpoints were considered in the model. The same principle - only considering the most strongly supported disease endpoints - was applied in the microbial dose-response modelling.

It is acknowledged that a range of other endpoints have been attributed to excessive arsenic consumption based on less conclusive evidence, including cancers of the kidney, liver and prostate as well as cardiovascular, endocrine, reproductive and cognitive effects (NRC 1999, 2001; Abernathy 2001).

The present study aimed to develop a model that could handle any arsenic concentration within the broad dynamic range likely to be relevant to the Bangladesh arsenic mitigation programmes. Therefore, for this study, dose-response models that use a continuous range of arsenic input values and that are tailored to application in Bangladesh were sought. A number of recent studies have described dose-response models specifically adapted to US circumstances (NRC 1999, 2001), optimised to cope with very low doses (3 to 20 µg/L) and a response in the US population (larger bodyweight and lower water consumption than Bangladesh). Another recent study that did focus on Bangladesh applied categorical dose inputs (categories of, rather than continuous, arsenic concentrations). Yu *et al*. (2003) describe dose-response models developed specifically for Bangladesh that provide a relationship between observed health effects in exposed populations and continuous values of measured arsenic concentrations wells used as the community water sources.

The dose-response models presented by Yu *et al*. (2003) enable prediction of all the disease endpoints selected for this study. The skin lesion (arsenicosis) predictions were to be based on the West Bengal data of Mazumder *et al*. (1998) but were subsequently omitted from the present study for the same reason as this endpoint was omitted by Lokuge *et al*. (2004) as there is no consensus upon which to base a DALY severity weight. A generic research need was identified in defining a DALY disease burden estimate for such conditions (described below). The skin cancer predictions are based on the analysis of Brown *et al* (1989), which is in turn based on Taiwanese data of Tseng *et al*. (1968) and Tseng (1977). Internal cancer (lung and bladder) predictions are based on the analysis of NRC (1999; 2001), which are in turn based on the Taiwanese data of Chen *et al*. (1985) and Wu *et al*. (1989).

In applying models fitted to data from South-western Taiwan and West Bengal, it was assumed that the bodyweight, nutritional status and direct and indirect volumetric water intakes of current Bangladeshi populations are reasonably similar to those of the historical populations to which the dose-response models were fitted. Note that such an assumption was not made by USEPA in translating observations from the Asian studies to the US since the bodyweights of the latter are significantly higher and water volumes consumed significantly lower and a correction factor was applied (NRC 2001).

No basis was found to apply any such correction factors for the Bangladesh situation the comparative data available suggested that the populations are reasonably comparable. It was therefore concluded that the Yu *et al*. (2003) models are the most appropriate yet published for the current study. For example, Watanabe *et al*. (2004) reported an average total (direct and indirect through incorporation into food and both boiled and unboiled) water consumption of 4.6 and 4 l/day for males and females respectively in Bangladesh which were very similar to values derived from a review of studies from Taiwan (4.5 and 3 l/day respectively) and West Bengal (5 and 4 l/day respectively). In addition, as noted by Lokuge *et al*. (2004), the current Bangladeshi population is fairly similar, in terms of relevant factors, to the Taiwanese population from which much of the arsenic dose-response data are derived. There are a number of projects underway that are seeking to develop revised dose-response models for arsenic exposure but these models are not at the point where they are ready to be shared.

Since the selected dose-response models were fitted to the relationship between observed health effects and the measured concentrations of arsenic in community water source, the arsenic concentration alone provided the model input for arsenic. Incidence rates provided the inputs to the DALY estimation so prevalence rates were converted to annual incidence rates by dividing prevalence by average symptom duration in years.

6.3.6 Microbial dose-response

The dose-response relationships for the model reference pathogens were based on reported human-feeding-trial (HFT) data as follows. For “virus” the rotavirus model of Gerba *et al* (1996) citing the HFT of Ward *et al* (1986) was applied with a P_{inf1} (probability of infection for dose of one) of 27% and an ID_{50} (the dose leading to a probability of infection of 50% of those exposed) of 6. This model was selected for the viral model reference pathogen since it was based on rotavirus, which is an endemic and routinely surveyed bacterial infection in Bangladesh (ICDDR,B, 2003). The beta-Poisson distribution was selected because as noted by Teunis *et al*. (1999) it has been corroborated and widely used since being proposed by Gerba *et al*. (1996) .

For “bacterium” the *Shigella dysenteriae* model of Holcomb *et al*. (1999) citing the HFT of Levine *et al*. (1973) was applied with a P_{inf1} of 1% and an ID_{50} of 219. This model was selected for bacterial model reference pathogen since it was based on *Shigella*, which is an endemic and routinely surveyed bacterial infection in Bangladesh (ICDDR,B, 2003). The Weibull-gamma relationship was selected because it provided the smallest over-estimate at below-threshold doses from the acceptable-fitting inflection models.

For “protozoan” the “unknown strain” model for *Cryptosporidium parvum* of Messner *et al*. (2001) citing the HFTs of DuPont *et al*. (1995), Okhuysen *et al*. (1999) and Chappell *et al*. (1999) was applied leading to P_{inf1} of 2.8% and an ID_{50} of 25. This model was selected for the protozoan model reference pathogen since it was based on

Cryptosporidium, which is generally a more environmentally mobile, persistent and infectious pathogen than the alternatives *Giardia* and *Entameoba*. The model has a further advantage because it was based on a hierarchical Bayesian analysis of human dose response to several strains, capturing the information from three HFTs providing more confidence in the model than those described for the alternatives *Giardia* and *Entameoba* (Teunis and Havelaar 2002).

The daily dose of pathogens consumed was converted to a daily probability of infection according to these dose-response relationships to give an infection endpoint prediction for each pathogen. The daily probability of infection was converted to an annual incidence of infection as described by Teunis *et al*. (1997), which provided the input to the DALY calculation.

6.3.7 Calculating Disability-Adjusted Life Years (DALYs)

In general, DALYs were determined as described for waterborne disease by WHO (2004) and Havelaar and Melse (2003). Where a number of alternatives were proposed, the developing-world assumption was applied. In addition, a number of modifications were made where relevant Bangladeshi data was available.

Life expectancy in Bangladesh at birth in 1999 was stated as 60.8 for males and 59.6 for females (BBS 2004). Average life expectancies at birth of 62 were, therefore, applied for both sexes in this study to incorporate a slight increase since 1999. This gave slightly different DALY values from those proposed by Havelaar and Melse (2003) who used a life expectancy at birth of around 80 years, which is the highest global average life expectancy (experienced by Japanese women). The use of the national life expectancy was felt to more realistically reflect the impact of diseases in Bangladesh and would avoid all diseases appearing to have a very large impact and masking differences in the health impact of different technologies. This is similar to the approach used in Uganda by Howard *et al*. (2005).

The ratio of males to females was 103.8:1 based on the draft 2001 census summary (BBS 2004) and where appropriate this ratio was applied in deriving averaged community disease burdens. The age distribution based on the 1991 census was applied as described by Yu *et al*. (2003) since more recent figures from the 2001 census were not available (the 1991 census was published in 1996 so the 2001 census is not anticipated until around 2006).

The rotavirus, *Cryptosporidium* and *E. coli* O157:H7 DALY disease burden estimates described by Havelaar and Melse (2003) were selected for viral, protozoal and bacterial diseases respectively. Sequelae beyond diarrhoea and death from diarrhoea, such as HUS and ESRD for bacteria and AIDS-related symptoms for protozoa, were excluded. This omission was consistent with the omission of the less well-supported disease endpoints for arsenic.

DALYs were determined for internal and skin cancer endpoints as described by Havelaar and Melse (2003). No global burden of disease values were described for arsenicosis skin lesions (Murray and Lopez, 1996) , which was also noted by Lokuge *et al* (2004) and Havelaar and Melse, (2003) such that this endpoint was omitted from the present study.

As an additional modification, background levels of immunity to the viral, bacterial and protozoan reference pathogens were assumed to be relatively high due to the high background levels of disease borne by hygiene-related and other routes of transmission. However, these assumptions are tentative and are based on the opinion of local health sector professionals from WHO, UNICEF and ICDDR,B rather than objective data. For the model viral reference pathogen, due to the ubiquity of rotavirus in Bangladesh (ICDDR,B, 2003), and its hygiene-related mode of transmission, it was assumed that those older than one year were immune and then remain immune due to repeated asymptomatic re-infection and exposure. Therefore, a susceptible fraction in the general population of only 1.6% (based on life expectancy of 62 years), tenfold lower than the 17% proposed by Havelaar and Melse (2003), was adopted.

For the protozoal and bacterial reference pathogens, the assumptions on background immunity of Havelaar and Melse (2003) based on developed world data were arbitrarily reduced by ten-fold to give a susceptible fraction of 7.1% and 9% respectively. This ten-fold difference may be reasonable given, for example, that bacterial pathogens such as *Shigella* and *Vibrio cholerae* have been virtually eliminated from developed countries (e.g. Hellard *et al* 2001) but that they are routinely isolated in Bangladesh in around 10% of hospitalised patients whose stools are sampled regardless of condition (ICDDR,B, 2003). The same analysis reveals rotaviral isolation frequencies around ten-fold higher than reasonably comparable developed world analyses (e.g. Hellard *et al* 2001 compared with ICDDR,B, 2003).

The probability of death per symptomatic case (CFR) for the viral and bacterial pathogens were set at 0.23%, a figure based on the 1991 BBS census for hospitalised deaths from diarrhoea in which of 1250 deaths were observed in 532,031 hospitalised diarrhoeal cases. The hospitalised are the more serious cases making this CFR a possible over-estimate. On the other hand, once hospitalised, interventions will reduce the probability of death compared to that faced by cases remaining in the community, leading to a potential under-estimate of the true CFR. These two factors may balance out and 0.23% is reasonably consistent with the 0.6% and 0.4% CFR estimated by Havelaar and Melse (2003) for the developing world. The generally less severe (in the immuno-competent) protozoan pathogens were assumed to be less fatal with a CFR of 0.01% being applied (Havelaar and Melse 2003, citing Hunter and Syed 2001). The analysis of Havelaar and Melse (2003), citing Hunter and Syed (2001), described a basis for setting CFRs of 0.001%, 0.01% and 0.1% for *Cryptosporidium*; we have selected the middle from these values for the present study.

In summary, the DALYs per microbial infection applied in the present study were 2.4×10^{-3} for virus, 1.3×10^{-2} for bacteria and 1.4×10^{-4} for protozoa. The DALYs per case of arsenic related cancer applied in the present study were 1.18 for skin cancer, 16.29 for lung cancer and 13.67 for bladder cancer.

6.4 Results

The microbial and arsenic DALYs of arsenic mitigation options are illustrated in Figures 6.4 and 6.5 respectively. Viral and bacterial pathogen concentrations dominated the disease burden estimates for the microbial DALY results with protozoal risks contributing relatively negligible risks to the total. At the lower TTC concentrations (≤ 244 cfu) the viral disease burden was the most significant contributor and at higher TTC concentrations (≥ 245) the bacterial disease burden began to dominate as the viral disease burden reached its saturation point. The median and lower 5 percentile disease burdens of DTW, RWHS and STW are low, while contaminated sample can pose significantly higher risk.

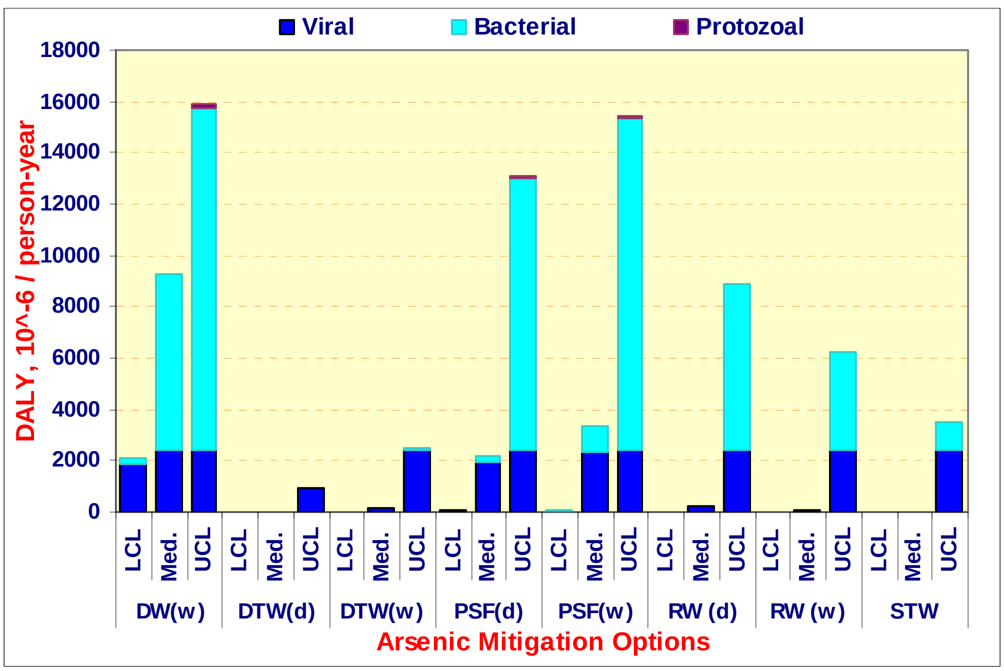


Figure 6. 4: Microbial DALY of Arsenic mitigation options

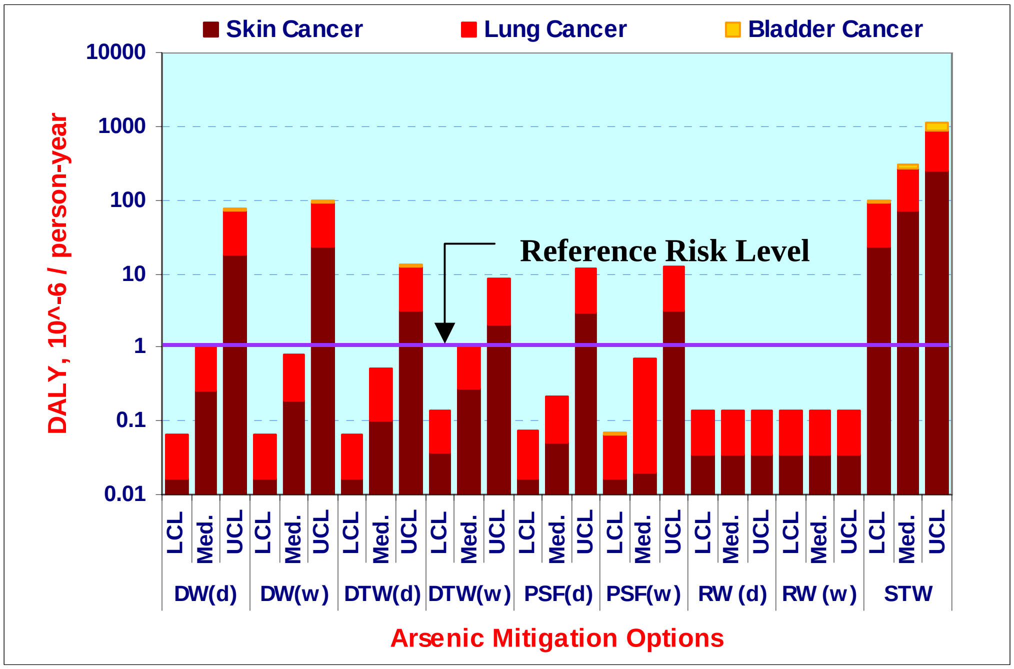


Figure 6.5: Arsenic DALYs of Arsenic mitigation options

For microbial quality, only the median risk for DTW in the dry season approached the WHO reference level of risk of 10^{-6} DALYs, although the lower confidence level for DTW in both seasons and RWHS in the wet season also approach or meet the reference level of risk. The median risks for DW and PSF do not meet the reference level of risk under any conditions. For DW even the lower confidence level always exceeds the reference level of risk significantly, while for PSF the lower confidence level in the dry season is low, but still significantly above the reference level of risk.

Skin cancer and lung cancer dominated the arsenic disease burden with lung cancer being a greater contributor than skin cancer across the dynamic range of the study. Contribution of bladder cancer to total arsenic DALY is negligible. The lower 5 percentile (LCL) and median arsenic DALY of all arsenic mitigation options were lower that the reference DALY of 1 per million population. Some level of arsenic contamination of DW, DTW and PSF can produce a upper 95 percentile DALY in the range from 10 to 100 per million. The LCL, median and UCL values of DALYs for shallow tubewells were 100, 304 and 1103 per million respectively (Figure 6.5).

The combined microbial and arsenic DALYs of arsenic mitigation options are shown in Figure 6.6. The greater proportions of the total DALYs attributed to each arsenic mitigation technology in both the seasons were microbial DALYs. Since the water sources having very low arsenic were selected for arsenic mitigation options, the arsenic DALYs for each of the option were insignificant as compared to microbial DALYs. In general, the lowest risk options in terms of disease burden were the DTWs and the

RWHSs, although both can indicate a significant upper 95th percentile microbial risk. The upper 95th percentile microbial disease burden was higher for DTW in the wet season while that of RWHS was higher in the dry season.

Based on the sanitary inspection, the microbial contamination of DTW is likely to from secondary sources probably from use of contaminated priming water and water quality could be successfully controlled by introduction of WSPs. Both DTWs and RWHS with some protection and good hygienic practices can provide water of low disease burden in both the seasons. The quality of water from PSF and DW suggests that improved designs are required to ensure safe water is supplied and that these should be incorporated into a water safety plan (WSP).

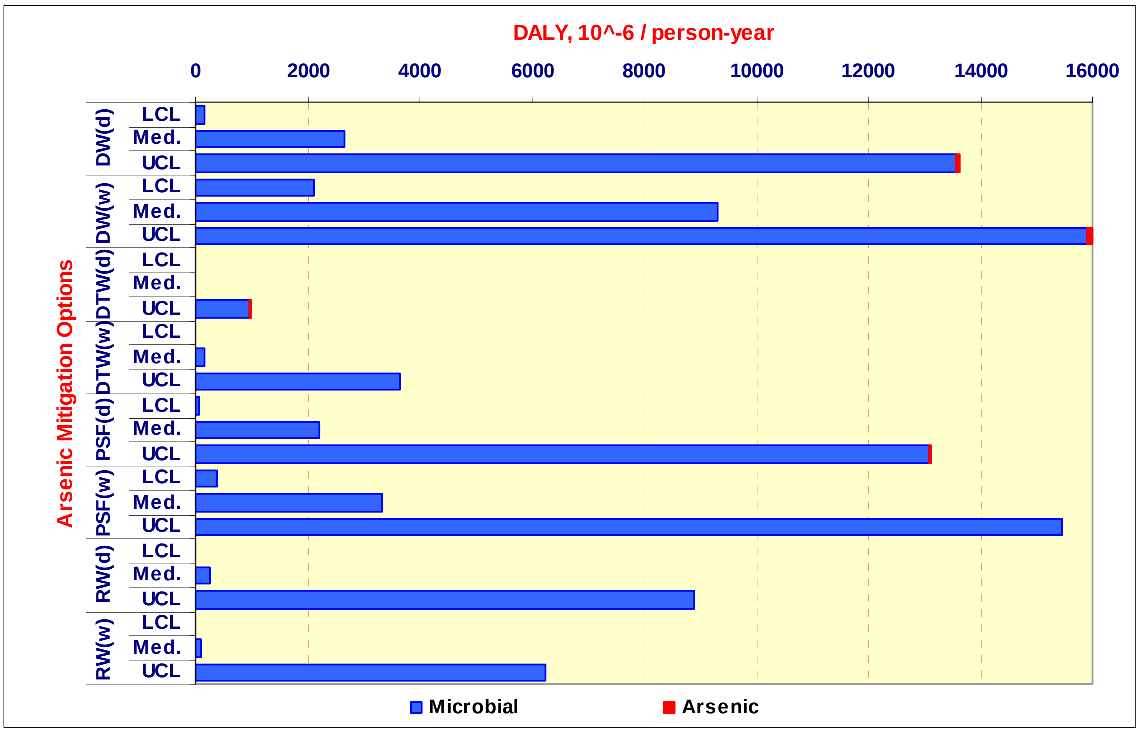


Figure 6.6 : Microbial and arsenic DALYs of arsenic mitigation options

6.5 Discussion

It was assumed that all water said to be *directly* consumed in the Watanabe *et al* (2004) study was *unboiled* as there were no indication to the contrary in the report, although this was not explicitly stated. This is not a criticism of the Watanabe *et al* (2004) study which was assessing water consumption for arsenic and not pathogen exposure such that boiling was not relevant to their analysis. However, in future assessments of water consumption, it would be useful to record not only direct consumption but also direct unboiled water consumption to enable the data to be more broadly used in microbial risk assessments.

The source of the TTC in RWHS in the dry season needs further investigation because this will have a significant impact on the estimated disease burden. If the TTC are derived from washing in from the occasional storms that occur in the late dry season, then the increase in TTC numbers would reflect an increase in risk of disease. If, however, the TTC are derived from re-growth within the tank during the dry season, then increases in TTC would not result in an increase in diarrhoeal disease burden (Hunter 2003). At present it is believed that the first mechanism is primarily at work because there were a number of significant storms during the late dry season and because the sanitary inspection showed that roof catchments were commonly not clean, but this warrants further study.

The proportion of TTC that are, in fact, of faecal origin is likely to be highly variable and a longitudinal study involving the typing of recovered TTC, or at least analysing for *E. coli*, would be desirable as a means of providing a basis for assessing the sanitary significance of TTC counts in Bangladesh. A move towards *E. coli* testing where reliable and practical is also warranted and the value of developing and using field kits and monitoring methods that specifically test for *E. coli* could improve the targeting of public health interventions.

The ratio of [*E. coli*]:[pathogen] is one of the most unsupported components of the model and one of largest sources of anticipated error. The variables affecting pathogen fate, survival and transport have been reviewed in detail (Ferguson *et al* 2003) and it should be possible to improve the validity of ratio estimates by modelling pathogen and *E. coli* fate and transport through the most plausible scenarios by which microbial contamination might arise for each technology. For example, birds are more likely to contribute to rainwater providing a basis for raising the [*E. coli*]:[virus] and [*E. coli*]:[protozoan] ratios. Similarly, dry season contamination is more likely to be subsurface, providing a basis for lowering [*E. coli*]:[virus] and raising [*E. coli*]:[protozoan] ratios. Such modifications can readily be made within the modelling framework applied.

QHRA models are limited in that they are predictive and involve extrapolating and estimating. Epidemiological validation of the model would not be simple but would theoretically possible. An epidemiological study seeking to validate the assumptions relating to arsenic would require decades to complete. An epidemiological study seeking to relate measured *E. coli* and/or TTC concentrations with disease burdens would be feasible years, but would require an extensive, representative study population that would prove difficult and expensive to recruit. The timeframe would also be likely to considerable if results were to be obtained that were valid beyond the specific population of any study.

7

SUMMARY OF FINDINGS

7.1 Water Quality

7.1.1 Microbial quality

- Microbial contamination of DW water was very common, as high as 94% of DWs were found contaminated with thermotolerant coliforms (TTC). This is consistent with findings of most of the organizations engaged in monitoring of DW water in Bangladesh. The magnitude of contamination of DW increased significantly in the monsoon season. More that 50% of the DWs showed a TTC count more than 500 cfu/100ml in the rainy season as compared to only 3% contaminated to that level in the dry season. Inflow of contaminated surface waters in the rainy season may be the cause of such an increase in the level of microbial contamination of DW water.

- The level of contamination of DW water suggests that DW water needs better sanitary protection and disinfection for safe operation as an alternative water supply option for arsenic mitigation. Disinfection is likely to be of particular importance in the monsoon season.

- Low levels of microbial contamination were found in 8% of DTWs. Poor sanitary conditions and priming of the wells with contaminated surface waters are the likely causes of microbial contamination of DTWs. A significant increase in the microbial contamination of DTW water was also observed in the monsoon season, with almost half the DTWs showing low-levels of TTC. The increase in contamination of water used for priming is likely contribute to such an increase in the contamination of DTW water in the wet season.

- Microbial contamination of PSF water was high. About 95% PSFs water samples were found contaminated in both the seasons with higher level of TTC in the monsoon season compared to dry season. High level of contamination of pond water, inadequate filter depth and poor maintenance of PSF are the main reasons for high microbial contamination of PSF water

- In case of RWHS, 43% of samples had TTC in the dry season and 63% in the monsoon season. Contamination was generally lower than PSF and DW but higher than DTW. Contamination appears to occur from contaminated roof top catchment, insanitary surroundings and poor handling of water in RWHS practiced in Bangladesh.

- The presence of *E.coli* in water samples from all arsenic mitigation options was found by confirmatory tests. It is considered that non-*E.coli* TTC were also of faecal origin.

7.1.2 Chemical quality

- Arsenic concentrations exceeding the BDS of 50 μg/L and WHO GV of 10 μg/L were found in 3% of DWs and 25% of DWs samples respectively. This study further confirmed that DWs are not universally arsenic-safe, but the number of DWs contaminated across the country is comparatively low. A visible improvement in the chemical quality, particularly arsenic content of DW water was observed in the monsoon season. Dilution of the top layer of the aquifer by infiltration of rain and surface waters of low mineral content may be the cause of improvement of chemical quality of DW water.

- None of DTWs sampled in this study had an arsenic concentration higher than the BDS and WHOGV. The mean arsenic content of DTW water was found to be 1 μg/L. However, arsenic contaminated DTWs ranging from 1-10% have been reported by different organizations. Arsenic contamination of DTWs is dependent on stratification of aquifers and aquicludes in the area concerned. Chemical quality of DTW remains almost unchanged except some small improvement in arsenic content of water in the monsoon season.

- Arsenic was found at very low levels in both PSF and RWHS waters, with only one pond showing a concentration exceeding BDS in the dry season. This pond could have been recharged by contaminated tubewell water. Arsenic in most samples from RWHS and PSF were below detection level.

- Iron and Manganese were present in both DW and DTW in excess of BDS and WHOGV. In 12% of samples collected from PSF in the dry season, the concentration of manganese exceeded the Bangladesh Standard of 0.1 mg/l for drinking water but none exceeded the WHO Guideline Value of 0.4 mg/l.

- The concentration of nitrate in DTW, PSF and RWHS waters was within BDS while that in 8% of DW water exceeded BDS. Ammonia in excess of BDS of 0.5mg/l was present in almost half of the wells (50% of DWs and 53% of DTWs) and in over 70% of samples from both PSF and RWHS in the dry season and in 31% PSF and 18% RWH samples in the monsoon season. The concentration of nitrate of water sample from both PSF and RWH was within acceptable limits.

- High pH values were observed in most of the water samples collected from RWHS. The median and mean values of pH were higher than acceptable highest level of 8.5 recommended in BDS for drinking water. The possible reason of such high pH value is leaching of calcium oxide from cement used for the construction of rainwater storage tank. However, the pH value of rainwater should improve with the curing of concrete. The pH levels of water from DW, DTW and PSF were close to neutral.

- The presence of zinc and lead was considered to be important in RWH from the metallic roofs used as catchment for rain water harvesting. The concentrations of these two heavy metals in water from RWHS were within acceptable levels for drinking water.

7.1.3 Physical quality

- DTW water was found clear with turbidity well within acceptable levels of BDS while 28 percent of DW water exceeded. About 50% of both DW and DTW water exceeded the BDS of 15 TCU for colour. About 28% of DW water had TDS higher than BDS, while only 3% DTW water exceeded the acceptable limit for TDS.

- The physical quality of water from both PSF and RWH measured by turbidity and total dissolved solid content was found to be within acceptable limit. The water from RWHS was of much superior quality in respect of physical quality as compared to DW, DTW and PSF waters.

7.2 Sanitary integrity

- Sanitary inspection shows that RWHS had the best sanitary protection with a median sanitary risk score in the 'low risk' category. About 21% of the RWHS were in the category requiring no action. The median risk scores of DW, DTW and PSF were in the 'intermediate to high risk' category in both seasons. Improved sanitary protection in all arsenic mitigation options is expected to improve the microbial quality of DW water.

- The sanitary inspection of PSF and RWHS showed that lack of protection was found at more than 90% of the ponds supplying water to PSFs and visible sign of contamination were found on 50% of the roof catchments of RWHS were most common sanitary risks. These factors deserve the highest attention in improving the sanitary protection of these water supplies. As both these factor are relatively simple, operational issues it suggests that training of caretakers needs to be improved and water safety plan approaches emphasised.

- The combined risk grading of DW in the category of 'very high risk' increased from 36% in the dry season to about 85% in the wet season. This change has resulted in a great deterioration of microbial quality of DW water in the wet season. In case of DTW a small change in combined risk grading from low risk in the dry season to 'intermediate risk' in wet season was observed. The quality of DTW water is much superior as compared to sanitary risk score because of water abstraction by DTW from a deeper protected aquifer. The PSF show an increase from 27% to 50% in the 'very high risk' category. RWHS maintained 40 to 50% of facilities in the 'intermediate to high risk' category.

- Analysis suggested that sanitary risk factors can be controlled through compliance with construction protocols, raising awareness within the community, behavioural changes within the community and ensuring community participation in planning, implementation, operation and maintenance. Disinfection of DW and PSF waters is essentially required for full control of microbial contamination and this should be incorporated within water safety plans.

- Among the risk factors '*fencing around water point*' is a socio-cultural issue. In a number of other countries, a lack of fencing has been shown to be linked to microbial contamination of water. However, fencing may lead to misunderstanding among communities in Bangladesh that collection of water is being restricted. This issue should be addressed carefully and will probably need strong motivation.

- *Insufficient width of apron* occurred at many water points. Since this issue is associated with cost and space, implementing agencies should consider this and try to prevent insufficient aprons being constructed in future programmes.

- The issue of *water ponding within 2 m*, *proper drainage* and *cracked apron* all contribute to risks by creating a source of hazards and routes into the water source that reduce the potential for attenuation. They are also good indicators of whether operation and maintenance for water safety is being successfully implemented. Addressing these issues requires training and raising community awareness.

7.3 Social aspects

7.3.1 User perception of distance to mitigation options

- The majority of households interviewed considered DW and DTW installed as being within an acceptable distance, only 12% consider the water points to be far from their houses. Almost 95% of households using a PSF considered this to be within an acceptable distance. The location of the mitigation options was acceptable to a majority of the users of the water points.

- Households considered to be rich were more likely to identify DW and DTW as being far from their home than either middle-class or poor households. In contrast, higher proportions of rich and mid-income groups consider PSF to be near, probably because of the fact that the ponds for installation of PSFs were given by these groups of households.

7.3.2 Use of mitigation options

- Most households used the mitigation option immediately after it was installed, with the highest number being among households using a PSF (98%). Within six months of the installation the figures for use of all arsenic mitigation options rose to 97% to 100%. This is indicative of not only social acceptability of the all the options but of a high level of awareness among people on adverse health impact of arsenic ingestion as well.

- Of households who did not start using the mitigation options immediately after installation mention distance as being the primary factor. The DW and PSF users also cited uncertainty about water the quality as being the reason for non-use of the mitigation option.

- The shift from red STW, distant green STW and other sources to newly installed arsenic mitigation options for drinking and cooking is satisfactory. The switch from a variety of sources including those contaminated with arsenic further reinforced the social acceptability of arsenic mitigation water supply options. However, some households used red STW and other sources for domestic proposes other than dinking and a small percentage of household depending on the option occasionally used red STW water for drinking.

- Households close to the mitigation option use more water for a variety of purposes including bathing and washing. The types of uses decrease with the increase in distance. Households that report the water point to be far only use the water for drinking and cooking and supplement water demand for other purposes by pond or water from tube well marked red.

- The average consumption of water for drinking varies from 3 to 5 lpcd. A study by NGO Forum shows that the daily household collection of drinking water for a rural family varies between 20 and 27 litres per day. This roughly corresponds to the finding of this assessment.

7.3.3 Satisfaction and attitude

- About 79% DW users, 96% DTW users, 95% PSF users and 59% RWHS users see the options being used by them as a permanent solution to the problem of arsenic contamination. Under the prevailing soco-economic conditions, poor households are likely to see community mitigation options as their only way of accessing arsenic-safe water for drinking and cooking. The promotion of a wider range of RWHS models including do-it-yourself systems can increase the use of the system among low-income groups.

- The respondents provided with a DW, DTW, PSF and RWHS were generally satisfied with the quality of the water but greater satisfaction was expressed in favour of RWHS, PSF and DTW waters as compared to DW water. There was little difference across the income groups regarding their satisfaction with arsenic mitigation options with respect to quality of water.

- The high proportion of use of, and user satisfaction with, arsenic mitigation options proves beyond doubt the social acceptability of all the options. From the social perspective there is no problem in promoting these as mitigation options in arsenic affected areas.

7.3.4 Operation and maintenance

- About 87% of the respondents knew of caretakers to look after the water point, but 32% of those who knew of caretakers were not very sure of who selected or who trained them. Responses varied from Union Parishad Chairmen to user community.

- The water points surveyed under RAAMO were installed within last two years. The repairs of operating water points in the last six months comprised minor work such as changing buckets, nuts or bolts. Most of the respondents asserted that the options were working well without any major problem while 28% using RWHS claimed that minor maintenance was necessary.

- Community-based facilities often fail due to inadequate operation and maintenance. The sanitary inspection data show that operation and maintenance is already beginning to deteriorate in many supplies and this may prove to be a problem in the future for community-based mitigation options. Future programmes need to commit more resources to develop local user-based mechanism for effective management and operation and maintenance of mitigation facilities.

7.3.5 User groups and community based organisations

- In cases where user groups or community based organisations (CBOs) were reported to have been formed, only small percentage of the respondents knew of their presence but were not sure as to when they were formed, for what purpose or who the members were.

- The assessment indicated that the process of user group or CBO formation was not very participatory and very few users actively participated in planning and implementation of the systems. The present process of user group and CBO formation, initiated by the sponsor to satisfy the project requirement, was not resulting in an effective mechanism for operation and maintenance of the systems. Lack of user participation may affect the sustainability of the water supply options.

- In planning and implementation of the mitigation options broad-based participation appears to have been absent and some respondents interpreted contribution for the water point as participation. No respondent, except those who had given land to install the facilities was found to be directly involved in decision making on the water point.

- Mitigation programmes tend to leave out the poor and the disadvantaged from planning and decision making process. The poor particularly have a higher stake as they are unable to own individual mitigation facilities and are likely to have a higher commitment to operation and maintenance of shared facilities. Mitigation programmes should widen participation to include users of all income categories and gender. Participation is required not only in planning, implementation and operation and maintenance of mitigation options but also in sharing of information on different aspects of arsenic and available technology options.

7.3.6 Awareness about arsenic

- Majority of the respondents have heard of arsenic in the last two years. In 84% of the cases, NGOs, word of mouth and radio/television were the main sources of information on arsenic. This is no surprise as 72% of the respondents were women who seldom venture out of home

- About two-thirds of the respondents knew that the mitigation option was installed because of arsenic contamination of existing tubewells and others thought it was just another water point to provide water to people. Considering the backdrop of absence of broad-based participation in installation of the mitigation option, this is not surprising.

- A majority of respondents knew that water from tubewells marked red should not be used, but 78% of the respondents did not know that water from red tubewells may be used for purposes other than drinking and cooking.

- Of the total households interviewed using the arsenic mitigation options, just over half knew that arsenic is a poison that gradually affects health and just under half could identify at least one physical symptom of arsenicosis. Only about 3% of the respondents knew that arsenicosis was not contagious.

- Future arsenic mitigation programmes that deliver community facilities must improve on building awareness giving emphasis on the use of water from red tubewells for purposes other than drinking and cooking; and that arsenicosis is not contagious. Awareness campaigns on arsenic and its ill affects should bear in mind that the best means of spreading messages are through radio and television, NGOs and word of mouth.

7.4 Health risk

- A quantitative health risk assessment (QHRA) model was developed and has shown to be robust in terms of calculating the likely disease burden associated with water sources based on three reference pathogens and arsenic. The QHRA provides a valuable input to decision-making processes in relation to water supply mitigation options.

- The viral and bacterial pathogen concentrations dominated the disease burden estimates where the contribution by protozoal pathogen to the total microbial DALY was negligible.

- Skin and lung cancers dominated the arsenic disease burden where lung cancer was the greater contributor to arsenic DALY than skin cancers across the range of values used for the study.

- Only DTW in the dry season had a median risk that was close to the WHO reference level of risk for microbial quality. Lower confidence levels for DTW in both seasons and RWHS in the wet season also meet or approach the reference level of risk. DW and PSF do not meet the reference level of risk under any conditions.

- The model shows that there is significant health risk substitution for DWs and PSFs with respect to pathogens. There is much lower risk substitution in DTWs and RWHSs in relation to either pathogens or other chemicals. Hence, DTW had the highest aggregate water quality followed by RWHS while DW and PSFhad the lowest aggregate water safety.

- The disease burden increased in the wet season with the greater deterioration of microbial water quality of DW. Although some improvement of arsenic content of water of both DW and DTW options were observed in the wet season, its influence on total DALY was insignificant as compared to microbial DALY. PSF DALY was a similar level to DW in the monsoon season and RWHS had a much lower DALY score in the monsoon season.

- The DTW and RWHS having low TTC and arsenic content can provide drinking water with the lowest risk in terms of disease burden. Additional intervention identified by water safety plans (WSs) would be required to get drinking water of acceptable disease burden from DW and PSF.

- The health risks from the water supplies could be effectively managed through WSPs. These are management systems that allow more effective control of water safety than solely relying on testing of water quality.

7.5 Concluding Remarks

- The process of risk assessment is useful in supporting revisions to strategy and programme implementation in terms of technology selection. This process should be continued and the QHRA tool developed should be used to evaluate disease burdens associated with a larger number of technologies. This will be done using some initial data from Unicef and WaterAid, but should be considered as an essential part of overall planning and decision-making.

- The sector should formalise an approach to using risk assessment to support decision-making. The development of a manual for the QHRA tool is being developed and training for key stakeholders in the use of QHRA should be considered to improve dissemination.

- Based the data collected in this study and data presented in other studies, it is clear that in overall terms DTW offer the best option with regard to public health risks and therefore, wherever feasible DTW should be the mitigation option of choice. The lack of an overall Pleistocene aquifer map and management strategy currently restricts the use of deep tubewells. It is essential that progress is made on developing a groundwater mapping and management strategy.

- The health risks associated with DW and PSF are much higher than DTW and RWHS. Nonetheless, it is clear that DW and PSF will continue to be key options for arsenic mitigation in many areas of Bangladesh. However, the data from this and other studies show that significant improvements in design, construction, operation and maintenance are required if these are to provide safe drinking water. Unicef have commissioned work to improve the PSF design and work supported by APSU will help in improving overall multi-stage filtration design. DWs are likely to require filtration and disinfection and the approaches being developed by AAN and APSU to improve dug well performance should be evaluated.

- RWHS offer low-risk options that can be located at the home. However, the difficulty in providing a year-round water supply and unaffordability for the poor, restricts the use of RWHS. There is a need to develop lower-cost designs whilst improving overall storage. The use of communal RWHS has to date be limited and mainly practiced at schools. The potential for developing communal RWHS further is an important area for ongoing study.

- Community participation appears to be relatively poor throughout the process of mitigation option selection, location and subsequent operation and maintenance. Greater effort is required to develop effective community-based processes that will support the sustainability of the options.

- Water safety plans should be implemented for all arsenic mitigation options to ensure that safe drinking-water is supplied in the long-term. The use of water safety plans would also support greater community participation because of its emphasis on working with communities to monitor and manage their water safety effectively. The current pilot projects supported by APSU and others undertaken by BWSPP, Unicef and DASCOH offer models to the wider sector on how to implement water safety plans in community supplies.

8

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Annex-1

PROPORTIONAL WEIGHTING TABLE - DUG WELLS AND DEEP TUBEWELLS					
Serial No	**Upazila**	**No. of DW**	**Cumulative no. DW**	**No. of DTW**	**Cumulative no. of DTW**
	BAMWSP				
1	Agailjhara	0		26	26
2	Banaipara	0	0	12	38
3	Gournadi	0	0	22	60
4	Faridganj	55	55	98	158
5	Hazigonj	14	69	95	253
6	Matlab	0	69	30	283
7	Dighulia	0	69	4	287
8	Raipur	0	69	34	321
9	Debhata	3	72	36	357
10	Kolaroa	18	90	35	392
11	Jhalakathi Sadar	0	90	8	400
12	Sarail	3	93	0	400
13	Alamdangha	5	98	0	400
14	Daudkandi	38	136	0	400
15	Laksham	40	176	0	400
16	Dohar	16	192	0	400
17	Kotalipara	10	202	0	400
18	Tungipara	3	205	0	400
19	Bhairab	2	207	0	400
20	Ulipur	2	209	0	400
21	Singair	5	214	0	400
22	Harirampur	20	234	0	400
23	Kularua	4	238	0	400
24	Kendua	5	243	0	400
25	Nalitabari	10	253	0	400
26	Raigonj	4	257	0	400
27	Gojaria	16	273	0	400
28	Lalpur	2	275	0	400
29	Sujanagar	1	276	0	400
30	Nowabgonj	5	281	0	400
	BAMWSP CAP		281		400
31	Gopalgonj	40	321	0	400
32	Uzirpur	0	321	96	496
33	Bheramara	84	405	0	496
34	Iswardi	92	497	0	496
	GOB-Unicef		497		496
35	Monirampur	115	612	0	496
36	Bhanga	49	661	0	496

Serial No	Upazila	No. of DW	Cumulative no. DW	No. of DTW	Cumulative no. of DTW
37	Barura	10	671	0	496
38	Nabinagar	57	728	0	496
39	Serajdikhan	39	767	0	496
40	Kalia	86	853	22	518
41	Rajoir	98	951	0	518
42	Shibchar	50	1001	0	518
43	Homna	47	1048	0	518
44	Brancharampur	34	1082	0	518
45	Damurhuda	31	1113	0	518
46	Babugonj	1	1114	19	537
	DPHE-Danida		1114		537
47	Noakhali Sadar	0	1114	271	808
48	Begumganj	0	1114	1006	1814
49	Laksmipur Sadar	0	1114	633	2447
50	Raipur	0	1114	461	2908
51	Ramgoti	0	1114	93	3001
52	Sonagazi	0	1114	113	3114
53	Barisal Sadar	0	1114	255	3369
54	Banaripara	0	1114	129	3498
55	Uzipur	0	1114	244	3742
56	Bakerganj	0	1114	410	4152
57	Pirojpur Sadar	0	1114	30	4182
	WPP		1114		4182
58	Shibgonj	15	1129	0	4182
59	Chapai sadar	14	1143	0	4182
60	Charghat	11	1154	0	4182
61	Bagha	1	1155	0	4182
62	Paba	21	1176	0	4182
63	Mohonpur	15	1191	0	4182
64	Bagmara	172	1363	0	4182
65	Bholahat	12	1375	0	4182
66	Gomostapur	71	1446	0	4182
	World Vision Bangladesh		1446		4182
67	Banderban	22	1468	34	4216
68	Dhobuara	0	1468	18	4234
69	Durgapur	5	1473	0	4234
70	Tarash	0	1473	200	4434
	AAN		1473		4434
71	Sharsha	51	1524	0	4434
	TOTAL		1524		4434

Water Quality analysis – parameters and methodologies(PSF and RWHS)

Parameter	Equipment Methodology	Field/Laboratory	Supplies (%)
Thermotolerant coliforms	Membrane filtration	Field	100
Confirmatory E. coli	Membrane filtration	Laboratory	≈ 30
Turbidity	Meter/Tube	Field	100
pH	Meter/probe	Field	100
Conductivity	Meter/probe	Field	100
Nitrogen species : • NO_3^- (PSF only) • NH_4^+ (PSF only)	Photometer	Field and laboratory	100
Color	Comparator	Laboratory	If field observation identifies color problem
Odor	H_2S	Laboratory	If field analysis identified smell problem
Arsenic	AAS	Laboratory	100 (for PSF) 25 (for RWHS)
Iron (for PSF only)	Photometer	Laboratory	20
Manganese (for PSF only)	Photometer	Laboratory	20
Phosphate (for PSF only)	Photometer	Laboratory	100
Zinc (for RWHs)	Photometer	Laboratory	20
Pb (for RWHs)	Photometer	Laboratory	20
Algae(for PSF only)	Photometer	Laboratory	100

Annex-3a

SANITARY SURVEY FORM FOR THE ASSESSMENT OF RISKS OF CONTAMINATION OF DUG WELL

I.	**Type of Facility**	**:**	**DUG WELL WITH HANDPUMP**
1.	General Information	:	Caretaker :………………………………………..
		:	District…………………..Upazila :………………
		:	Union…………………Village………………….
2.	Code Number	:……………………………………..…..	
3.	Date of Visit	:………………………………………	

4. Water sample taken?……………… Sample No……………….. FC/100ml…………..…

II. Specific Diagnostic Information for Assessment

		Risk
1.	Is there a latrine within 10m of the Dug Well?	Y/N
2.	Is the nearest source of faecal pollution on higher ground than the Dug Well?	Y/N
3.	Are there any other sources of faecal pollution within 10m of the Dug Well?	Y/N
4.	Is the drainage faulty allowing ponding within 2m of the Dug Well?	Y/N
5.	Is the drainage channel cracked, broken or need cleaning?	Y/N
6.	Is the apron less than 2m in width?	Y/N
7.	Does spilt water collect in the apron area?	Y/N
8.	Is the handpump loose at the point of attachment to apron	Y/N
9.	Is the apron cracked or insanitary?	Y/N)
10.	Is the fence missing or faulty?	Y/N

Total Score of Risks ….…………/10

Risk score: 9-10 = Very high; 6-8 = High; 3-5 = Medium; 0-3 = Low

III Results and Recommendations:

The following important points of risks were noted: (List nos. 1-10)

Signature of sanitarian………………………………

Annex-3c

SANITARY SURVEY FORM FOR THE ASSESSMENT OF RISKS OF CONTAMINATION OF DEEP HAND TUBEWELLS

I.	**Type of Facility**	**:**	**TUBEWELL WITH NO. 6 HANDPUMP**
1.	General Information	:	Caretaker :………………………………………..
		:	District…………………..Upazila :………………
		:	Union………………….Village………………….
2.	Code Number	:…………………………………….…..	
3.	Date of Visit	:………………………………………	

4. Water sample taken?……………… Sample No……………….. FC/100ml…………..…

II. Specific Diagnostic Information for Assessment

		Risk
1.	Is there a latrine within 10m of the DHTW?	Y/N
2.	Are there any other sources of pollution within 10m of DHTW?	Y/N
3.	Is the nearest source of pollution on higher ground than the DHTW?	Y/N
4.	Is the drainage faulty allowing ponding within 2m of the DHTW?	Y/N
5.	Is the drainage channel cracked, broken or need cleaning?	Y/N
6.	Is the apron less than 1m in width?	Y/N
7.	Does spilt water collect in the apron area?	Y/N
8.	Is the apron cracked or damaged?	Y/N
9.	Is the handpump loose at the point of attachment to apron	Y/N
10.	Is the fencing missing or faulty	Y/N

Total Score of Risks ….…………/10

Risk score: 9-10 = Very high; 6-8 = High; 3-5 = Medium; 0-3 = Low

III Results and Recommendations:

The following important points of risks were noted: (List nos. 1-10)

Signature of sanitarian.………………………………

SANITARY SURVEY FORM FOR THE ASSESSMENT OF RISKS OF CONTAMINATION OF SHALLOW HAND TUBEWELLS

I. Type of Facility : SHALLOW TUBEWELL (NO. 6 HANDPUMP)

1. General Information : Caretaker :………………………………………..
   : District…………………..Upazila :………………
   : Union…………………Village………………….
2. Code Number :……………………………….…..
3. Date of Visit :………………………………………
4. Water sample taken?……………… Sample No……………….. FC/100ml…………..…

II. Specific Diagnostic Information for Assessment

		Risk
1.	Is there a latrine within 10m of the SHTW?	Y/N
2.	Are there any other sources of faecal pollution within 10m of DHTW?	Y/N
3.	Is the nearest source of faecal pollution on higher ground than the DHTW?	Y/N
4.	Is the drainage faulty allowing ponding within 2m of the DHTW?	Y/N
5.	Is the drainage channel cracked, broken or need cleaning?	Y/N
6.	Is the apron less than 1m in width?	Y/N
7.	Does spilt water collect in the apron area?	Y/N
8.	Is the apron cracked or insanitary?	Y/N
9.	Is the handpump loose at the point of attachment to apron	Y/N
10.	Is the fencing missing or faulty	Y/N

Total Score of Risks ….…………/10

Risk score: 9-10 = Very high; 6-8 = High; 3-5 = Medium; 0-3 = Low

III Results and Recommendations:

The following important points of risks were noted: (List nos. 1-10)

Signature of sanitarian………………………………

Annex - 4a

Questionnaire for Social Assessment of Pond Sand Filter (PSF) in Arsenic Affected Areas

Household # | | | |

Date of interview # | | | | | | |

Day Month Year

Area	**Code**	**Name**
Division		
District		
Upazila/Town		
Union/Ward		
Village		

Questionnaire:

A01. Name and Sex of the Respondent --

No	Sex	Code
1	**Male**	
2	**Female**	

A02. Father's/Husband's Name --

A03. Age of the respondent ______,

A04. Number of persons in the household

No.		Number	Code
1	**Male/ female**		
2	**Child (<15)**		

A 05. House type

No.	House type	Code
1	**Kuncha**	
2	**CI sheet roof**	
3	**CI sheet roof and walls**	
4	**Brick walls**	
5	**Brick walls and concrete roof**	
6	**Others**	

A 06. Access to facilities

No.		Code
1	**Electricity**	
2	**Television**	
3	**Radio**	
4	**Sanitary Latrine**	
5	**Kuncha Latrine**	
6	**Pond**	
7	**Others**	

A07. Level of Education of respondent

No		Code
1	**Farming**	
2	**Landless Farmer**	
3	**Business**	
4	**Day labourer**	
5	**Rickshaw / van puller**	
6	**Service**	
7	**Others**	

A08. Primary Activity of the family head

No		Code
1	**Illiterate**	
2	**Primary (1-5)**	
3	**Secondary (6-10)**	
4	**Higher Secondary**	
5	**Degree**	
6	**Masters and above**	

A09. Comments of enumerator on family status

No.		Code
1	**Poor**	
2	**Middle class**	
3	**Rich**	

A10. Distance of water source

No		Code
1	**Very near**	
2	**Slightly remote**	
3	**Remote**	

Questions related to PSF

B01. When was the PSF installed?

No		Code
1	**Less than a year**	
2	**Between one and two years**	
3	**More than two years**	

B02. Why was the PSF installed?

No		Code
1	**No water point in the vicinity**	
2	**Arsenic in existing water point**	
3	**Others (specify)**	

B03. When did you start using the water from the water point?

No		Code
1	**Since its installation**	
2	**Six months after installation**	
3	**Others (specify)**	

B04. If case of delayed use, why did you not use the water from the PSF so long?

No		Code
1	**Too far**	
2	**Access restricted**	
3	**Not reliable**	
4	**Others (specify)**	

B05. For what purpose do you use PSF water?

No		Code
1	**Only for drinking**	
2	**For drinking and cooking**	
3	**For bathing and washing**	
4	**Others**	

B06. Do you use water from any other sources?

No		Code
1	**Yes**	
2	**No**	

B07. Which sources of water do you use for other purposes?

No		Code
1	**Red Marked Tubewell**	
2	**Pond/River**	
3	**Others**	

B08. Do you use water from tube well marked red

No		Code
1	**Yes**	
2	**No**	

B09. If yes, for what purpose?

No		Code
1	Drinking	
2	Drinking/Cooking	
3	Bathing and washing	
4	Others (specify)	

B10. How much water you use from PSF everyday?

No		Code
1	**1-4 Kalsi (10- 40 liters)**	
2	**5-10 Kalsi (41-100 Liters)**	
3	**>10 Kalsi (> 100 liters)**	

B11. Is the collected water adequate for intended use?

No		Code
1	**Yes**	
2	**No**	

B12. What is the quality of water?

No		Code
1	**Satisfactory**	
2	**Not Satisfactory (specify reasons)**	

If the answer is 'not satisfactory' ask question number 13

B13. Why the quality of water is not satisfactory?

No		Code
1	Odor Problem	
2	Color Problem	
3	Others (specify)	

B14. From where you used to collect water before installation of PSF?

No		Code
1	From nearby Green Marked Tubewell	
2	Red Marked Tubewell	
3	Pond/River Water	
4	Others	

B15. When did you first hear about arsenic?

No		Code
1	Less than a year ago	
2	One to two years ago	
3	More than two years ago	

B 16. From where did you first hear about arsenic?

No		Code
1	DPHE/project personnel	
2	CBOs	
3	NGOs	
4	Word of mouth	
5	Union Parishad members/chairman	
6	Radio/TV	
7	Posters/newspaper	
8	Others	

B17. When did you know that the tube well you use has arsenic?

No		Code
1	Less than a year ago	
2	One to two years ago	
3	More than two years ago	

B18. What did you hear about arsenic?

No		Code
1	Arsenic is a poison that affects health	
2	Arsenocosis is not contagious	
3	Arsenic contaminated water may be used for all purposes except drinking/cooking	
4	Tube wells marked green are arsenic safe	
5	Tube wells marked red are arsenic contaminated	
6	Others (specify)	

B19. How did you know about arsenic in your tube well?

No		Code
1	CBO tested the tube well	
2	NGO tested the tube well	
3	DPHE tested the tube well	
4	Word of mouth	
5	Union Parishad member/chairman	
6	Others	

B20. Has the new installation been performing well since installation?

No		Code
1	**Yes**	
2	**No** **If no, what are the problems?**	

B21. How many times was it repaired after installation?

No		Code
1	**Minor repairs**	
2	**Major repairs**	
3	**No repairs needed**	

B22. What type of maintenance was needed?

No		Code
1	**Scraping of Sand bed**	
2	**Sand bed replacement**	
3	**Washing of Roughing bed materials**	
4	**Hand Pump Repair**	
5	**Others**	

B23. Has the community formed a CBO?

No		Code
1	**Yes When?..........**	
2	**No**	

B24. If yes, is it still working

No		Code
1	**Yes**	
2	**No**	

B25. If no, why (specify)?

No		Code
1		
2		
3		
4		

B26. Is there a caretaker for the PSF?

No		Code
1	**Yes**	
2	**No**	

B27. Who selected the caretaker?

No		Code
1	User Community (CBO)	
2	Union Parishad member/chairman	
3	Project/provider	
4	Others	
5	**Does not know**	

B28. Who provided the training for the caretaker?

No		Code
1	Project/provider	
2	NGO	
3	Others	
4	No training provided	
5	**Does not know**	

B29. How long was the training?

No		Code
1	Half day	
2	One day	
3	Two day	
4	More than two days	
5	Not Known	

B30. What issues did the training cover?

No		Code
1	Installation	
2	Operation and Maintenance	
3	Health and Hygiene	
4	Others	
5	Not Known	

B31. If ‘no’ to Q. 26, who takes care and does minor O&M of the water point?

No		Code
1	CBO	
2	Household nearest to PSF	
3	Household that provided the land for PSF	
4	Household that provided the maximum contribution	
5	Others	

B32. How many households use the water points?

No		Code
1	**____ Households**	
2	**Not known**	

B33. Do all households in this locality use the water point?

No		Code
1	**Yes**	
2	**No**	

B34. It no to Q 33 why do you think the remaining households are not using the water point?

No		Code
1	**Very far**	
2	**Use pond water**	
3	**Households have opportunity to use other arsenic free water sources**	
4	**Access restricted**	
5	**Others**	

B35. How has the site for the water point been selected?

No		Code
1	Through consensus of users	
2	By influential members of the community	
3	By the household that made the highest contribution	
4	Others	

B 36. Do you have free access to the PSF?

No		Code
1	**Yes**	
2	**No**	

B37. If no why?

No		Code
1	Caretaker's restriction	
2	Site owner's restriction	
3	Others (specify)	

B38. Did you or anyone in your household have a role in selection of the technology?

No		Code
1	**Yes**	
2	**No**	

B39. If yes, how (specify)?

No		Code
1	Village meeting	
2	CBO meeting	
3	Contribution money	
4	Others (specify)	

B40. How much money did you pay for PSF installation?

No		Code
1	**……………………..Tk**	
2	**Didn't pay**	
3	**Not known**	

B41. Is the caretaker paid any monthly salary?

No		Code
1	**Yes**	
2	**No**	

B42. If yes, how much?

No		Code
1	**…………………………..Tk**	

B43.Do you consider this PSF as permanent solution?

No		Code
1	**Yes**	
2	**No**	

B44. If yes, for what reason?

No		Code
1	**Good Water Quality**	
2	**Arsenic Free**	
3	**No health problems**	
4	**Water is always available**	
5	**Others (specify)**	

B45. If 'No', why?

No		Code
1		
2		
3		

Additional comments from the respondent (if any):

Comments of the enumerator:

Annex 4-b

Questionnaire for Social Assessment of Rain Water Harvesting System (RWHS) in Arsenic Affected Areas

Household # | | | |

Date of interview # | | | | | | |

Day Month year

Area	Code	Name
Division		
District		
Upazila/Town		
Union/Ward		
Village		

Questionnaire:

A01. Name and Sex of the Respondent ---

No	Sex	Code
1	**Male**	
2	**Female**	

A02. Father's/Husband's Name ---

A03. Age of the respondent ______,

A04. Number of persons in the household

No.		Number	Code
1	**Male/ female**		
2	**Child (<15)**		

A 05. House type

No.	House type	Code
1	**Kuncha**	
2	**CI sheet roof**	
3	**CI sheet roof and walls**	
4	**Brick walls**	
5	**Brick walls and concrete roof**	
6	**Others**	

A 06. Access to facilities

No.		Code
1	**Electricity**	
2	**Television**	
3	**Radio**	
4	**Sanitary Latrine**	
5	**Kuncha Latrine**	
6	**Pond**	
7	**Others**	

A07. Level of Education of respondent:

No		Code
1	**Farming**	
2	**Landless Farmer**	
3	**Business**	
4	**Day labourer**	
5	**Rickshaw / van puller**	
6	**Service**	
7	**Others**	

A08. Primary Activity

No		Code
1	**Illiterate**	
2	**Primary (1-5)**	
3	**Secondary (6-10)**	
4	**Higher Secondary**	
5	**Degree**	
6	**Masters and above**	

A09. Comments of enumerator on family status

No		Code
1	**Poor**	
2	**Middle class**	
3	**Rich**	

A10. Distance of water source :

No		Code
1	**Very near**	
2	**Slightly remote**	
3	**Remote**	

Questions related to RWHS

B01. Capacity of RWHS storage tank:

No		Code
1	**1000-3000 liters**	
2	**3000-5000 liters**	
3	**>5000 liters**	

B02. Type of storage tank:

No		Code
1	**Ferro-cement**	
2	**GI sheet**	
3	**Others (specify)**	

B03. Water Use Pattern:

No		Code
1	**Household Use**	
2	**Community Use**	

If the RWHS is community type, ask the following questions?

B04. How many households use the water points?

No		Code
1	**____ Households**	
2	**Not known**	

B05. Do all households in this locality use the RWHS?

No		Code
1	**Yes**	
2	**No**	

B06. It no to Q 05 why do you think the remaining households are not using the RWHS?

No		Code
1	**Very far**	
2	**Use pond water**	
3	**Households have opportunity to use other arsenic free water sources**	
4	**Access restricted**	
5	**Others**	

B07. Distance of respondent's house from RWHS

No		Code
1	**Near**	
2	**Slightly far**	
3	**Far**	

Actual distance of respondent's house from RWHS………………meters

B08. When was the RWHS installed?

No		Code
1	**Less than a year**	
2	**Between one and two years**	
3	**More than two years**	

B09. Why was the RWHS installed?

No		Code
1	**No water point in the vicinity**	
2	**Arsenic in existing water point**	
3	**Others (specify)**	

B10. When did you start using the water from the RWHS?

No		Code
1	**Since its installation**	
2	**Six months after installation**	
3	**Others (specify)**	

B11. If use after a delay in installation, why did you not use the water from the new tube well?

No		Code
1	**Too far**	
2	**Access restricted**	
3	**Not reliable**	
4	**Others (specify)**	

B12. From where you used to water before installation of RWHS?

No		Code
1	**From nearby Green Tubewell**	
2	**From red tubewell**	
3	**River or pond water**	
4	**Others**	

B13. For what purpose do you use RWHS water?

No		Code
1	**Only for drinking**	
2	**For drinking and cooking**	
3	**For bathing and washing**	
4	**Others**	

B14. Do you use water from any other sources?

No		Code
1	**Yes**	
2	**No**	

B15. Upon which sources of water you depend for other water uses?

No		Code
1	**Red Marked Tubewell**	
2	**Pond/River**	
3	**Others**	

B16. When did you first hear about arsenic?

No		Code
1	Less than a year ago	
2	One to two years ago	
3	More than two years ago	

B 17. From where did you first hear about arsenic?

No		Code
1	DPHE/project personnel	
2	CBOs	
3	NGOs	
4	Word of mouth	
5	Union Parishad members/chairman	
6	Radio/TV	
7	Posters/newspaper	
8	Others	

B18. When did you know that the tube well you use has arsenic?

No		Code
1	Less than a year ago	
2	One to two years ago	
3	More than two years ago	

B19. What did you hear about arsenic?

No		Code
1	Arsenic is a poison that affects health	
2	Arsenocosis is not contagious	
3	Arsenic contaminated water may be used for all purposes except drinking/cooking	
4	Tube wells marked green are arsenic safe	
5	Tube wells marked red are arsenic contaminated	
6	Others (specify)	

B20. How did you know about arsenic in your tube well?

No		Code
1	CBO tested the tube well	
2	NGO tested the tube well	
3	DPHE tested the tube well	
4	Word of mouth	
5	Union Parishad member/chairman	
6	Others	

B21. Has the new installation been performing well since installation?

No		Code
1	**Yes**	
2	**No** **If no, what are the problems?**	

B22. How many times did it need repair after installation?

No		Number	Code
1	**Minor repairs**		
2	**Major repairs**		
3	**No repairs needed**		

B23. What type of repair was needed?

No		Code
1	**Cleaning of catchments/ roof**	
2	**Cleaning of gutter**	
3	**Cleaning of storage tank**	
4	**Flushing of first rain water**	
5	**Others**	

B24. Who takes care the RWHS?

No		Code
1	**Owner of the RWHS**	
2	**Project**	
3	**Others**	

B25. Is the caretaker paid any monthly salary?

No		Code
1	**Yes**	
2	**No**	

B26. If yes, how much?

No		Code
1	**…………………………..Tk**	

B27. Have you or any family members received training?

No		Code
1	**Yes**	
2	**No**	

B28. Who trained the caretaker?

No		Code
1	**Project/ Donor**	
2	**DPHE**	
3	**Others**	

B29. How is the quality of water?

No		Code
1	**Satisfactory**	
2	**Not Satisfactory (specify reasons)**	

B30. How long the RWHS remain dry?

No		Code
1	**One to two months**	
2	**Two to four months**	
3	**More than four months**	
4	**Water never dried out**	

B31. What do you do when collected water is dried out?

No		Code
1	**Green tubewell water is used**	
2	**Unboiled pond or river water**	
3	**Boiled pond or river water**	
4	**Red tubewell water is used**	
5	**Others**	

B32. Has the RWHS installed upon your choice?

No		Code
1	**Yes**	
2	**No**	

B33. If ‘Yes’, Why did you choose RWHS as a water supply option?

No		Code
1	**Cheap**	
2	**Rainwater is arsenic free**	
3	**Others**	

B34. Is the collected water adequate?

No		Code
1	**Yes**	
2	**No**	

B35. Do you use water from tube well marked red?

No		Code
1	**Yes**	
2	**No**	

B36. If yes, for what purpose?

No		Code
1	Drinking	
2	Drinking/Cooking	
3	Bathing and washing	
4	Others (specify)	

B37. How much water you use from RWHS everyday?

No		Code
1	**1-4 Kalsi (10- 40 liters)**	
2	**5-10 Kalsi (41-100 Liters)**	
3	**>10 Kalsi (> 100 liters)**	

If the RWHS is community based, ask the questions no. (B35 – B51)

B38. How was the RWHS site selected?

No		Code
1	**By RWHS volunteer**	
2	**By influential person/ family of the community**	
3	**By the family contributed most**	
4	**Others**	

B39. Are you satisfied with the RWHS location?

No		Code
1	**Yes**	
2	**No**	

B40. Do you have free access to the RWHS?

No		Code
1	**Yes**	
2	**No**	

B41. If no why?

No		Code
1	Caretaker’s restriction	
2	Site owner’s restriction	
3	Others (specify)	

B42. Did you or anyone of your family have a role in selection of the technology?

No		Code
1	**Yes**	
2	**No**	

B43. If yes, how (specify)?

No		Code
1	Village meeting	
2	CBO meeting	
3	Contribution money	
4	Others (specify)	

B44. Has the community formed a CBO?

No		Code
1	**Yes** **When?..........**	
2	**No**	

B45. If yes, is it still working

No		Code
1	**Yes**	
2	**No**	

B46. If no, why (specify)?

No		Code
1		
2		
3		
4		

B47. Is there a caretaker for the RWHS?

No		Code
1	**Yes**	
2	**No**	

B48. Who selected the caretaker?

No		Code
1	User Community (CBO)	
2	Union Parishad member/chairman	
3	Project/provider	
4	Others	
5	**Does not know**	

B49. Who provided the training for the caretaker?

No		Code
1	Project/provider	
2	NGO	
3	Others	
4	**Not known**	

B50. How long was the training?

No		Code
1	Half day	
2	One day	
3	Two day	
4	More than two days	
5	Not Known	

B51. What issues were included in the training?

No		Code
1	Installation method	
2	Operation and Maintenance	
3	Health and Hygiene	
4	Others	
5	Not Known	

B52. If 'no' to Q. 46, who takes care and does minor O&M of the RWHS?

No		Code
1	CBO	
2	Household nearest to RWHS	
3	Household that provided the site	
4	Household that provided the maximum contribution	
5	Others	

B53.Do you consider this RWHS as permanent solution?

No		Code
1	**Yes**	
2	**No**	

B54. If yes, for what reason?

No		Code
1	**Good Water Quality**	
2	**Arsenic Free**	
3	**No health problems**	
4	**Water is available always**	
5	**Others (specify)**	

B55. If ‘No’, why?

No		Code
1		
2		
3		

Additional comments from the respondent (if any):

Comments of the enumerator: