# Kanchan Arsenic Filter (KAF) – Research and Implementation of an Appropriate Drinking Water Solution for Rural Nepal

# カンチャン砒素フィルター（KAF）
# －ネパール農村部のための適切な飲料水解決策の調査と実行

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**ABSTRACT**
Many people in the rural Terai region of Nepal lack access to safe drinking water. Tube well drinking water sources from a number of districts are contaminated with arsenic. In addition, many of these sources are microbially contaminated. Those who drink contaminated water may suffer from preventable water-borne diseases such as diarrhea, stunting, skin lesions, and cancer. It is estimated that 0.7 million people are affected by arsenic alone, and many more by pathogens.

To combat this problem, a team comprised of researchers from Massachusetts Institute of Technology (MIT), together with two local partners, Environment & Public Health Organization (ENPHO), and Rural Water Supply and Sanitation Support Programme (RWSSSP), have conducted investigations since 1999 to develop sustainable technologies for arsenic mitigation.

We have developed an award-winning household water filter, the Kanchan Arsenic Filter (KAF), for simultaneous arsenic and pathogen removal, constructed using locally available labor and materials. The design is optimized based on the socio-economic conditions in the southern, or Terai region of Nepal where arsenic is found. Pilot studies since September 2002 show high user acceptance, financial sustainability and excellent technical performance. User and prominent NGOs in Nepal consider the KAF as the best among all household arsenic filters available.

The first part of this paper will explain the technology development process, the technical performance of the filters, and the socio-economic evaluation of this innovation. The second part of this paper will describe the World Bank DM2003 award, and the plan to implement the KAF project throughout the Terai region. The objectives of this project includes the establishment of local entrepreneurs for a financially sustainable distribution mechanism, the capacity-building of local people towards long-term, user-participatory safe water provision, the dissemination of KAF information from a central technology center, as well as networking with other water supply implementers to expand this project to new areas.

Keywords: Arsenic, Water Treatment, Sustainable Development, Rural Development, Implementation

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## Introduction

Although access to safe drinking water is a basic human right (WHO, 2003a), millions of Nepalis are denied this right. Nepal is the 12th poorest country in the world, with 45% of its 24 million people living below the poverty line (World Bank, 2002; UNICEF, 2003). In the rural Terai region of southern Nepal where population density is greatest, basic safe water and health services are often unavailable. Villagers suffer from diseases related to unsafe water supply and sanitization. It is estimated that 90% of the rural Terai population receives their drinking water supply from tube wells, but many of these water sources are arsenic and/or microbially contaminated (ENPHO, 2003). Arsenic is a poison that causes skin diseases and cancers (WHO, 2002). Water-borne pathogens can cause diarrhea, cholera, stunting and other ill effects.

Despite growing recognition of the immediacy of this crisis, many previous aid projects have failed in rural areas (UN, 2002). This is because a number of the available arsenic and household purification technologies have serious drawbacks, including complex production methods, high maintenance, high costs, insufficient flow rate, and/or reliance on materials unavailable in remote villages. In addition, most technologies treat arsenic and pathogens independently, resulting in complicated treatment operations. Another cause of previous failures is implementation deficiencies including ineffective technology transfer, confusing non-government organization (NGO) responsibilities, financial non-sustainability, lack of user education and contribution, and inadequate long-term monitoring capacity.

Many villagers have no choice but to drink contaminated water. Over 0.7 million people drink arsenic contaminated water daily, and many more are affected by microbial contamination. Often children are most vulnerable to these preventable water-borne diseases.

## MIT Nepal Water Project - Development of Arsenic Mitigation Options

To provide safe water and health improvement for the people affected by contaminated drinking water in the Terai, Massachusetts Institute of Technology (MIT), in partnership with two local organizations, Environment & Public Health Organization (ENPHO) and Rural Water Supply and Sanitation Support Programme (RWSSSP), have conducted collaborative research to develop mitigation options. Since 1999, 5 teams of over 30 faculty, students and staff from the Civil and Environmental Engineering Master of Engineering program and from the MIT Sloan Business School have traveled to Nepal for field research, as part of the MIT Nepal Water Project. The MIT Nepal Water Project focuses on the development of household-scale sustainable technology. The research process for arsenic mitigation is based on a 4-step approach. These four steps include: background research, Phase I evaluation, Phase II evaluation, and implementation.

### Step 1: Background Research

An arsenic treatment technologies database has been setup at MIT to compile information from around the world on available remediation options applicable at the household or community scale. . The database includes information such as principal arsenic removal mechanisms, technical performance, construction methods, operation & maintenance requirements, cost, flow rate and other relevant data. Over 50 technologies are currently in the online database http://web.mit.edu/murcott/www/arsenic

In addition to the database, field data has been collected. MIT students have traveled to a number of Terai districts (Kaplivastu, Rupandeshi, Nawalparasi, Bara, Parsa, Rautahat), as well as to the capital, Kathmandu, to test water for arsenic contamination. Other water quality parameters such as pH, iron concentration, phosphate concentration, manganese concentration, arsenic speciation, water temperature, indicator organism counts have also been collected. Furthermore, students have observed local health and socio-economic conditions through interviews with local villagers, health officials, government representatives, business enterprises, etc.

Step 2: Phase I Evaluation

In the Phase I Evaluation, eight technologies in the database were selected based on preliminary screening. Evaluation included “appropriate” (low cost, simple, using local materials, rural focus), green and sustainability criteria. The technologies we screened appeared to be suitable for the conditions in Nepal, and might potentially be implemented as a sustainable mitigation option. These selected technologies included 3-Kolshi, jerry can, iron-oxide coated sand, activated alumina, activated alumina manganese oxide, coagulation & filtration system (2-Kolshi), community-level arsenic removal plants, and the Kanchan Arsenic Filter (KAF). These technologies were evaluated in the laboratory and in the field based on three main criteria – technical performance, social acceptability, and economic affordability. For technical performances, questions such as “Can arsenic be reduced to either the Interim Nepali National Standard of 50 ug/L or the WHO guideline of 10 ug/L?” and “Can the filter produce sufficient flow rate for a large family?” were asked. For social acceptability, questions such as “Can the technology be easily manufactured by local labor using locally available materials?”, and “Is the technology accepted by rural Nepali culture and traditions?” were evaluated. Finally, financial affordability refers to whether the technology is affordable to the rural villagers who typically earn less than $1 per day.

From the Phase I Evaluation, three technologies passed the technical, social, and financial evaluation: the 3-Kolshi System, 2-Kolshi System, and the Kanchan Arsenic Filter. The 3-Kolshi System, developed and applied in Bangladesh based on a traditional water treatment practice, consists of three clay pots stacked vertically. For that system, arsenic removal is based on adsorption to iron filings contained in the top pot. The 2-Kolshi System was also developed in West Bengal and Bangladesh and adapted to Nepal. The system consists of a 20-liter plastic mixing bucket, coagulant chemical, and a filtration unit consisting of two pots. Arsenic is removal by coagulation and co-precipitation mechanisms. The Kanchan Arsenic Filter (KAF) was developed through the MIT/ENPHO/RWSSSP partnership. It is consists of a plastic or concrete container filled with gravel, sand, and iron nails. Arsenic is removed by adsorption onto iron nails.

Step 3: Phase II Evaluation

The Phase II evaluation involved pilot studies of these three technologies. Starting in 2002, for three to twelve months, a total of about 60 Three-Kolshi systems, 100 Two-Kolshi systems, and 20 KAF systems were distributed and monitored by ENPHO and RWSSSP, with MIT’s assistance. The three technologies were subjected to more vigorous assessment in terms of technical, social, and financial criteria. For technical performance, arsenic samples were split, tested in the field and sent to the ENPHO Laboratory for analysis. Iron and bacteria removal efficiencies were studied as well. For social acceptance, interviews with the users were conducted to obtain their feedbacks on issues including operation and maintenance difficulties, perceived health benefits from the filter, flow rate adequacy, and water taste and appearance. Feedback from ENPHO and RWSSSP on issues related to filter construction, distribution network setup, availability of materials, scale-up potential, etc. were also recorded and factored into the Phase II evaluation. For financial affordability, a detail breakdown of the capital cost, long-term running cost, and a simple willingness-to-pay study were determined. Table 1 shows the Phase II evaluation summary of these technologies.

**Table 1**. Phase II Evaluation Summary for the 3-Kolshi, 2-Kolshi, and Kanchan Arsenic Filter

| | **3-Kolshi** | **2-Kolshi** | **KAF** |
|---|---|---|---|
| **Arsenic removal** | 95-99% | 80-90% | 90-95% |
| **Iron removal** | Not tested | Not tested | 93-99% |
| **Flow rate** | 1-5L/hr | 1-5L/hr | 10-15L/hr |
| **Materials availability** | ★★★ | ★ | ★★★ |
| **Easy construction** | ★★★ | ★★★ | ★★★ |
| **Simple O&M** | ★★ | ★★ | ★★★ |
| **Long-term sustainability** | ★★ | ★ | ★★★ |
| **User acceptance** | ★★ | ★ | ★★★ |
| **Low initial cost** | ★★★ | ★★★ | ★★ |
| **Low running cost** | ★★ | ★★ | ★★★ |
| **Overall Ranking** | **2nd** | **3rd** | **Best** |

★ **= poor** ★★ **= moderate** ★★★ **= good**

The Phase II evaluation showed that the Kanchan Arsenic Filter was the best among the three filters. Although the three filters yielded comparable results in terms of technical performance and financial affordability, the KAF was clearly more socially acceptable than the other two systems. For example, the 3-Kolshi can filter water at an average flow rate of 1-5 L/hr. Many users complained about the insufficient flow, and some users skipped filtration when they had no time. The filter also tends to clog (to < 1 L/hr) after a few months of usage. For the 2-Kolshi, the distribution of a necessary chemical proved to be a real challenge. This specialized chemical was not usually available in the local marketplace, and had to be shipped from Kathmandu to remote rural areas. Besides the high shipping cost, the chemicals can only reached large market centers, not the local marketplace that are accessible to most rural villagers. Also, some users complained about the amount of work necessary to run the coagulation system (e.g. add chemical, stir, wait 30 minutes).

Step 4: Implementation
Implementation will be discussed in a latter section.

**Details of the Kanchan Arsenic Filter (KAF)**
The Kanchan Arsenic Filter (formerly called the Arsenic Biosand Filter, ABF) is a built on the platform of a slow sand filter, modified to include arsenic removal capability. Slow sand filters were developed in the 1820s in Scotland by Robert Thom and in England by James Simpson and became successfully established in Europe by the end of the 19$^{th}$ century. The Davnor BioSand Filter (BSF) is a variation developed in the 1980s. It is a household-scale intermittent slow sand filter developed by Dr. David Manz, formerly of the University of Calgary, Canada, now of Davnor Water Treatment Technologies Ltd. The Davnor BSF has been tested by several governments, research and health institutions, and NGOs in Canada, Vietnam, Brazil, Nicaragua, Bangladesh, and other countries. The Kanchan Arsenic Filter combines both these concepts – slow sand and an intermittent household-scale system with the innovation of a diffuser basin containing iron nails for arsenic removal.

This KAF is constructed of simple materials available in the local markets of Nepal. These materials include plastic containers, PVC pipes, iron nails, brick, sand, and gravel. The construction of the filter can be carried out by locally trained technicians using simple tools such as wrenches and hammers. Figure 1 shows the components of the Kanchan Arsenic Filter (KAF).

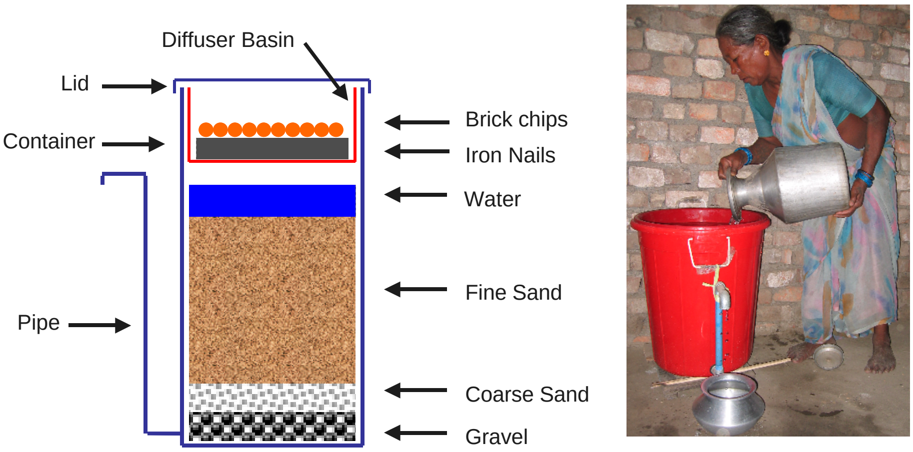


**Figure 1 Cross-Section of the Kanchan Arsenic Filter (KAF) Showing Major Components**

In the KAF, arsenic is removed by adsorption onto the surface of rusted iron nails (i.e. ferric hydroxide). Pathogens such as bacteria are removed mostly by physical straining provided by the fine sand layer, by attachment to previously removed particles, and, to a less degree, by biological predation occurring in the top few centimeters of the sand. Over the course of the project, four different versions (concrete square, concrete round, Hilltake plastic, Gem505 plastic) of the KAF have been designed, each representing an improvement in performance and cost. The latest Gem505 KAF (shown in Figure 1) was designed in March 2004. The Gem505 has a design flow rate of 15 L/hr.

Between February 2004 and May 2004, a blanket testing of all existing KAF in the Terai region were performed. Table 2 shows the arsenic removal performance of the KAF. The average arsenic removal efficiency is about 90-93%. It is found that over 95% of the filters produced water within the Nepali guideline of 50 ppb. The remaining filters were later found to be defective in the installation process. Therefore it is important to construct the filters properly to ensure performance. Table 3 shows the iron removal performance of the KAF. The average iron removal efficiency is about 90-95%. A few filters were unable to significantly remove iron. They were later found to be defective in the installation process as well. Iron, unlike arsenic, is not a health threat. Iron affects the aesthetics of the water (e.g. taste, color, odor). High iron removal usually improves the users' acceptance of the filter because the high iron concentration makes the water orange/red color and undesirable taste.

**Table 2. Arsenic field test results on 966 KAFs (including all four versions) in the Terai region**

| Influent Arsenic Concentration (ppb) \ Effluent Arsenic Concentration (ppb) | 500 | 450 | 400 | 350 | 300 | 250 | 200 | 150 | 100 | 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 | ND |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **500** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 5 |
| **450** | | 3 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 1 | 8 |
| **400** | | | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 2 | 2 | 10 |
| **350** | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 1 | 3 | 15 |
| **300** | | | | | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 3 | 1 | 28 |
| **250** | | | | | | 2 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 2 | 2 | 1 | 2 | 27 |
| **200** | | | | | | | 2 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 32 |
| **150** | | | | | | | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 40 |
| **100** | | | | | | | | | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 3 | 8 | 99 |
| **90** | | | | | | | | | | 1 | 0 | 2 | 1 | 0 | 0 | 0 | 3 | 6 | 86 |
| **80** | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 57 |
| **70** | | | | | | | | | | | | 0 | 0 | 0 | 0 | 3 | 0 | 3 | 42 |
| **60** | | | | | | | | | | | | | 0 | 0 | 1 | 2 | 5 | 13 | 34 |
| **50** | | | | | | | | | | | | | | 0 | 0 | 0 | 2 | 5 | 71 |
| **40** | | | | | | | | | | | | | | | 0 | 0 | 0 | 2 | 21 |
| **30** | | | | | | | | | | | | | | | | 0 | 0 | 0 | 17 |
| **20** | | | | | | | | | | | | | | | | | 0 | 1 | 44 |
| **10** | | | | | | | | | | | | | | | | | | 0 | 12 |
| **ND** | | | | | | | | | | | | | | | | | | | 189 |

*Figure indicates number of filters*

**Table 3. Iron field test results on 953 KAFs (including all four versions) in the Terai region**

| Influent Iron Conc. (ppm) \ Effluent Iron Concentration (ppm) | 10 | 5 | 3 | 2 | 1 | 0.5 | 0.3 | 0.1 | ND |
|---|---|---|---|---|---|---|---|---|---|
| **10** | 1 | 6 | 13 | 1 | 62 | 0 | 42 | 1 | 17 |
| **5** | | 0 | 1 | 1 | 45 | 0 | 73 | 1 | 47 |
| **3** | | | 0 | 0 | 1 | 0 | 11 | 0 | 69 |
| **2** | | | | 0 | 1 | 0 | 0 | 0 | 32 |
| **1** | | | | | 0 | 0 | 1 | 0 | 210 |
| **0.5** | | | | | | 0 | 0 | 0 | 26 |
| **0.3** | | | | | | | 2 | 0 | 193 |
| **0.1** | | | | | | | | 0 | 2 |
| **ND** | | | | | | | | | 94 |

*Figure indicates number of filters*

Bacteria removal performance of the KAF is still under investigation. While laboratory experiments showed total coliform removal of up to 2-3 log, preliminary field experiments showed an average of 0.3-0.4 log removal only. These conflicting data between lab and field experience will be clarified by ongoing research at MIT and in Nepal.

**Table 4. Gem505 design cost breakdown**

| | *Gem505 ($US)* |
|---|---|
| **Container and Lid** | $5.55 |
| **Basin** | $1.03 |
| **Piping System** | $1.82 |
| **Sand & Gravel** | $0.04 |
| **Iron Nails 5 kg** | $4.79 |
| **Transportation of sand & gravel** | $0.27 |
| **Transportation of container & piping** | $0.41 |
| **Labour** | $0.74 |
| **Documentation** | $0.34 |
| **Tools** | $0.74 |
| **Total Per Unit Cost** | **$15.73** |

The cost breakdown of the Gem505 filter is shown in Table 4. There is no long-term running cost except the expense to replace iron nails. It is still uncertain as to how long before the iron nails need to be replaced. The first filters were installed 1.5 years ago, and the arsenic adsorption capacity of the nails has not been exhausted yet.

**Implementation - World Bank Development Marketplace (DM) Global Competition 2003**

In order to promote KAF throughout the arsenic-affected districts in the Terai, a partnership comprised of MIT, ENPHO, and RWSSSP jointly applied for, and won an award in the 2003 World Bank Development Marketplace (DM) Competition. The project duration is from February 2004 to January 2005. Key activities in this project include the following:

- A KAF Technology Center at ENPHO in Kathmandu has been established to provide information and training to all interested groups. Technology details, construction manuals, research findings, education materials, and other relevant information are available at the KAF Center.
- 26 local entrepreneurs from 10 arsenic-affected districts have been trained and certified as local agents to provide KAF to users. These entrepreneurs are local non-government organizations (NGOs), Red Cross, or community groups who are active in water supply. The entrepreneurs were trained in filter construction, installation, operation, maintenance, troubleshooting, and entrepreneurships techniques. Entrepreneurs gather all KAF construction materials from local suppliers at a wholesale price, construct the filter and pack it into ready-to-use packages, and sell to individual customers or institutional buyers (e.g. donors) at a profit. The profit ensures the financial sustainability of the entrepreneurs. Also, they can provide filter installation/repair/testing services at an additional cost.
- 30 arsenic-affected Village Development Committees (VDC) have been selected for orientation. Orientation about health, water management, treatment options, and KAF information have been provided to VDC members, health posts, teachers, local NGOs, and interested agencies. Within these VDC, ward-level education workshops (total 150) on health, hygiene, water-related diseases, KAF operation and maintenance, and subsidy information have been given to villagers.
- A database of KAF distribution in Nepal has been created. Filter information such as user name, number of users, and GPS location has been collected. Technical performance parameters such as arsenic removal, pH, and flow rate are recorded. There are currently about 1,000 filters in operation at the time of this writing. It is expected that about 2,000 filters will be in operation by the end of 2004.
- Research, development, and testing of improved filter designs based on field observations and feedback from users is ongoing.
- A national workshop will be held in Kathmandu in January 2005 to present the project findings. A written report will be produced. Also, findings have been disseminated in Nepal and internationally through conference presentations, journals, internet, TV, newspaper and radio.

**Is the Project Sustainable?**

Many appropriate technologies and many water supply and/or treatment projects in the developing world fail. We think this project might be sustainable because both the technology is simple, uses local materials and is liked by users and the because the implementation approach is relies on local entrepreneurs who profit from their enterprise.

<u>Sustainable Technology</u>

- Systems thinking (e.g.holistic, iterative and multi-disciplinary) inherent in the concept of sustainable development has been applied to the design of the KAF.
- As opposed to many technologies designed in first-world laboratories far removed from the users, the KAF was designed on-site in arsenic and microbially-affected villages. Technological design was placed within social, economical, and political constraints of Nepal (Murcott, 2001; 2003).
- It is manufactured by local labour using materials available in rural Nepal.
- The filter operation and maintenance is easy, suitable for the often uneducated rural villagers.
- The filtered water tastes and looks significantly better than untreated water (according to many users) so users will continue to use the filter.

Sustainable Implementation

- Local entrepreneurs were trained to manufacture KAF and provide services (installation, maintenance, testing, etc) at business locations that are easily accessible to most villages.
- Information about water contamination, treatment options, KAF, and cost were provided to villagers through workshops such that they can make individual informed decision to protect their health.
- The capacity of existing local authorities like Village Development Committee (VDC) and health posts to support safe water initiatives were strengthened, rather than relying on the often ineffective remote central authority and/or top-down distribution.
- The implementation scheme made use of existing and functioning distribution networks and infrastructure rather creating new networks/infrastructure; therefore reducing risk of failure and negative impacts.
- For entrepreneurs to be financially sustainable, their monthly profit (calculated by multiplying unit sales by margin per unit) must be greater than their monthly fixed cost. In this case, their fixed cost is minimal because these entrepreneurs are well-established local NGOs and community clubs that have their own financial support for their premises and staff. Depending on the KAF demand, they can easily hire temporary staff to increase their filter production on an as-needed basis.

**Future Plans and Challenges Ahead**

The arsenic and microbial contamination problem in Nepal cannot be solved overnight. Long-term sustained efforts must be continued in the coming years in order to bring the maximum benefits to the population. When the current World Bank project is completed in January 2005, additional implementation programs must be continued. Future plans and challenges ahead for the MIT Nepal Water Project and its partners include:

- How to scale-up project to reach 0.7 millions in Nepal?
- Increase villagers' awareness of health and water through media, workshops, drama, music, especially targeting the poorest, the least educated, and those living in remote western areas
- Seeking additional funds to subsidize filters for the poorest villagers
- Providing refresher training and certification to entrepreneurs
- Continuing research to improve filter design
- Influencing government and policy-makers to acknowledge the seriousness of arsenic contamination and to take necessary actions
- Disseminating the KAF technology to the development community to gain their feedback, support and collaboration

**Conclusions**

The KAF is a modest but sincere attempt to provide a sustainable solution to the arsenic and microbial contaminated drinking water problems in Nepal. The KAF technology itself and the implementation plan are appropriate for the context of Nepal.

Arsenic and microbial contamination cause water-borne diseases that can be mitigated by the KAF. Therefore, this project directly improves the health of thousands of people in the rural Terai. In addition, less sickness will contributes to greater worker productivity. This in turns leads to overall economic growth and poverty alleviation. Also, the avoidance for women and children of long travel to collect better quality water will produce time saving. The extra time will allow them to pursue productive work such as attending schools or taking caring of family members. Furthermore, family cohesion will be enhanced by preventing divorce and rejection of marriage of some women who show signs of skin diseases due to arsenic poisoning (ENPHO, 2001).

It is expected that this project will raise awareness among rural villagers about water quality and health such that they can make informed decisions to protect their health. This project makes the KAF technology available at the grassroots level in a sustainable manner. Furthermore, the success of our implementation program in strengthening communities' capacity and responsibility in safe water provision can be a springboard for other community initiatives such as improved water availability, hygiene and sanitation services.

For more information, visit http://ceemeng.mit.edu/~water


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