Nepali Water Solutions Inc.

Advisor: Susan Murcott

Point-of-Use Water Treatment in Nepal

Group members:

Heather Lukacs
Chian Siong Low
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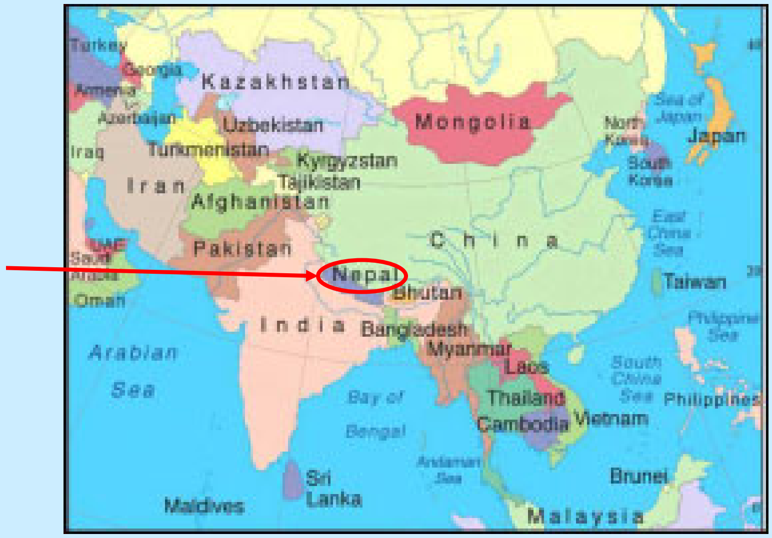
Xuan Gao
Luca Morganti
Barika Poole
Jeff Hwang
Tommy Ngai

April 12th 2002

Presentation Outline

1. Project Background
2. Filtration
3. Chlorine Disinfection
4. Arsenic Remediation
5. Tubewell Maintenance
6. Q & A

Where is Nepal?



Nepal Situation (UNICEF, Dec 2000)

Average income:
$US 210/capita/year
Pop. below poverty line:
42%

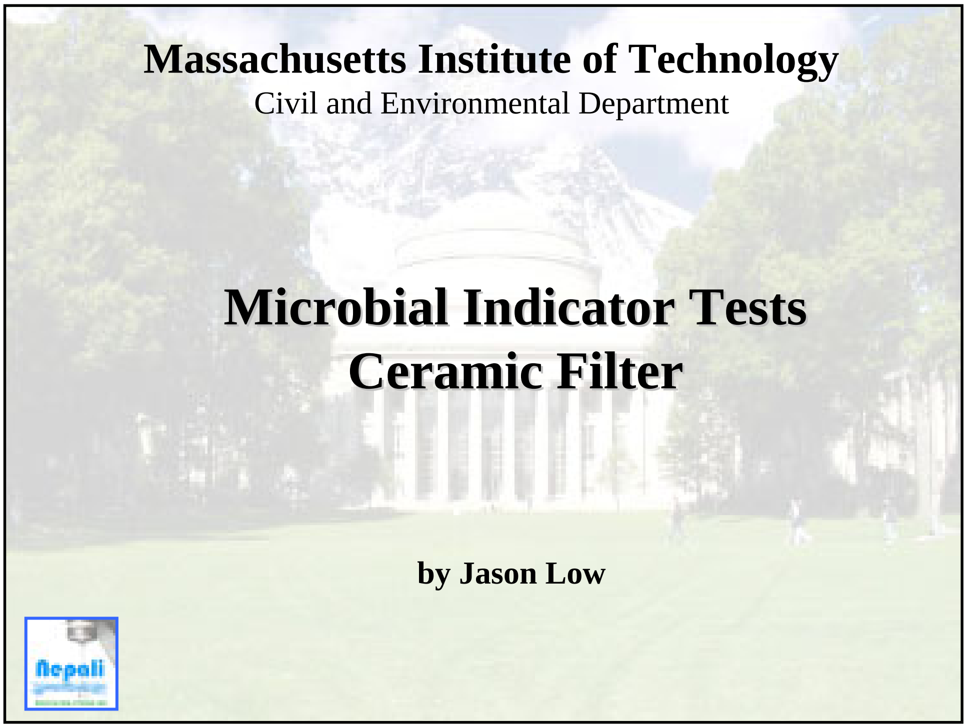
Moderate to severe Stunting:	54%
Infant mortality:	75/1000 live births
Diarrheal illnesses:	44000 child death/year
Life expectancy:	58

Nepal Project (1999-2000)

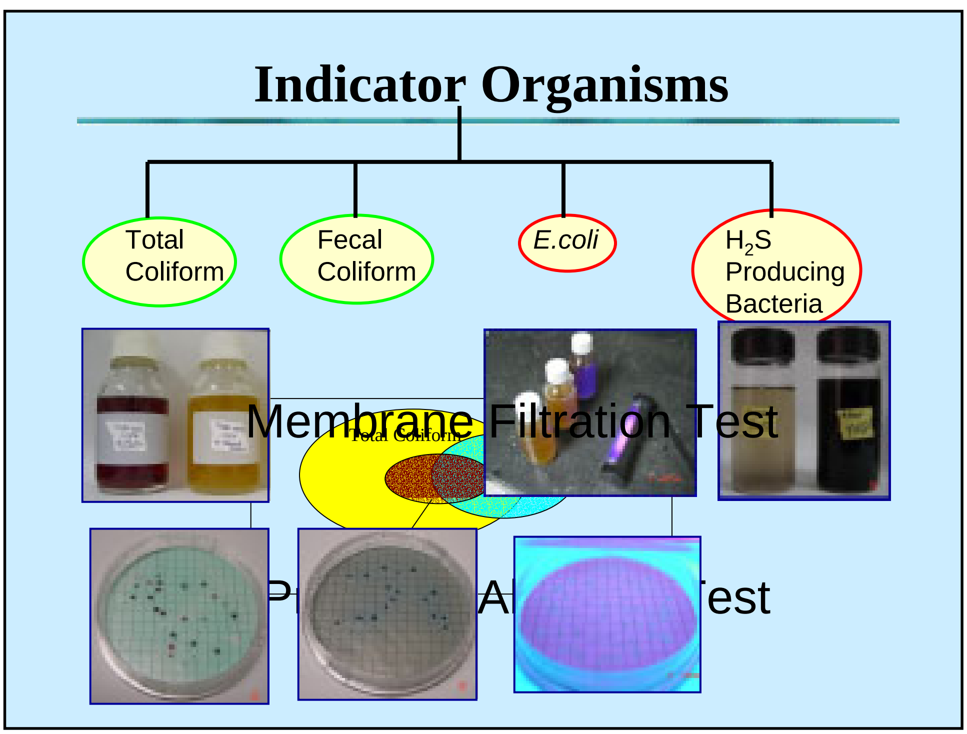
- Drinking Water Quality Survey
  - Microbial Contamination
  - Arsenic Contamination
  - Nitrate & Ammonia Contamination
- Point-of-Use Water Treatment
  - Coagulation
  - Filtration
  - Disinfection

Nepal Project (2000-2001)

- Drinking Water Quality Survey
  - Microbial Contamination
  - Arsenic Contamination
- Point-of-Use Water Treatment
  - Filtration (Biosand Filtration, CerCor Filtration)
  - Disinfection (SODIS)
  - Arsenic Removal (Three-gagri, Jerry Can, ATU)
- Social Acceptability/BSF Pilot Study Evaluation



Massachusetts Institute of Technology
Civil and Environmental Department
Microbial Indicator Tests
Ceramic Filter
by Jason Low



Indicator Organisms
Total Coliform
Fecal Coliform
E.coli
H_2S Producing Bacteria
Membrane Filtration Test
Total Coliform

TC and H_2S P/A Test

- Result interpretations within 48 hours:

Absence	Presence	%Confirm
Purple	Yellow	33 to 76
No foam	Foam*	74 to 98

- Reliable, easy to interpret results
- Good sensitivity

From Literature

Temp	H_2S +
22ºC	48 hrs
37ºC	18 hrs
44ºC	36 hrs

From Field (Hannah)

Temp	H_2S +
35ºC	24 hrs
5-25ºC	24-72 hrs

- Same advantages

Performance of P/A Tests

	P/A (TC)	P/A (H2S)
Estimated Sensitivity (CFU/100ml)	2 TC	27 TC, 4 FC, 2 *E*
Agreement with TC[1]	97%	74%
Agreement with FC[1]	76%	79%
Agreement with *E.coli*[1]	92%	70%
False Positives with TC	0%	2%
False Positives with FC	24%	12%
False Positives with *E.coli*	8%	8%

[1] Assume detection limit of 1 CFU/100ml

Performance of P/A Tests

	P/A (TC)	P/A (H2S)
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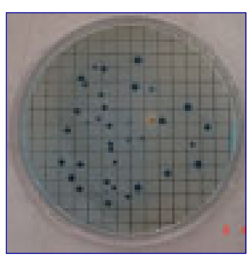
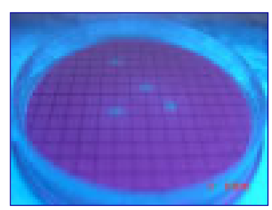
Membrane Filtration

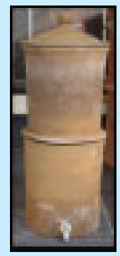
Total Coliform	Fecal Coliform	*E.coli*
		
m-Coliblue24	m-FC	EC with MUG
$1.50 ea	$0.825 ea	**<$0.10 ea (self-prepared)**

• Ease of interpretation, cost, ease of preparation

Filter Making in Thimi

- Filter prototype making at Hari Govinda's, Thimi.
- Terracotta filters made from various compositions.

- Manufacturing Process
  - **Prepare** raw materials.
  - **Mix** by hand.
  - **Press** in mold.
  - **Dry** (5-7 days).
  - **Fire** (1000°C).
  - **Cement** into ceramic/metal containers.
  - **Dry** (2 days).



Ceramic Filter Performance

	TERAFIL (in MIT)	TERAFIL (in ENPHO)	2 Thimi Filters
Flowrate	1 - 2 L/hr	5 - 7 L/hr	0.2 - 0.3 L/hr
Turbidity removal	83 – 93%	97 – 99%	56 – 84%
Total coliform removal	96 – 99.9%	94 – 99.5%	96 – 99.6%
Fecal coliform/ *E.coli* removal	N.A.	96 – 100%	96 – 100%

Ceramic Filter Performance

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Total coliform removal	96 – 99.9%	**94 – 99.5%**	96 – 99.6%
Fecal coliform/ *E.coli* removal	N.A.	**96 – 100%**	96 – 100%

Conclusions

- Indicator for POU treatment efficiency:

  MF → Fecal Coliform

- Indicator for drinking water safety:

  P/A → H_2S bacteria
  MF → Fecal Coliform and *E.coli*

- Terracotta ceramic filter:

  Adequate Flowrates
  Excellent Turbidity Removal
  Good Microbial Removal
  Cheap
  Locally Available Material

Massachusetts Institute of Technology
Civil and Environmental Department

Lumbini, Nepal

Well Survey

and

Household Water Treatment Pilot Studies

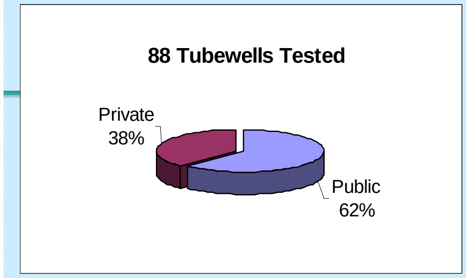
by Heather Lukacs

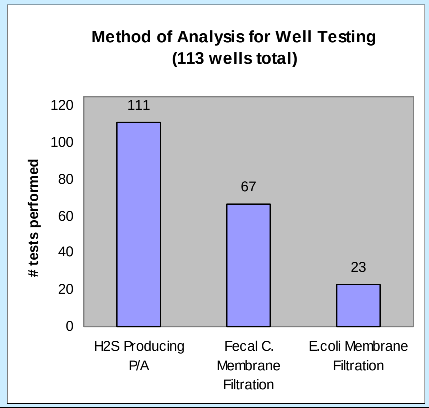
& Hannah Sullivan

Lumbini, Nepal

International Buddhist Society (IBS)

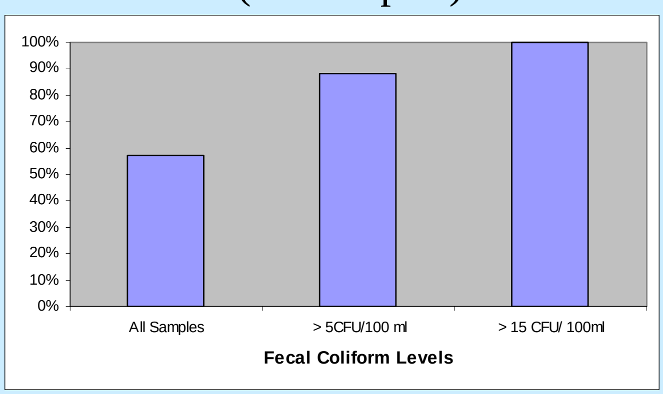
- -17 Villages
- -10,000 people
- - Health Clinic
- - Educational Outreach





H_2S – Fecal Coliform Test Correlation

(67 Samples)



Conclusion:

H_2S valuable for ruling out high level contamination.

Well Testing Results

	Public	Private
Positive for H_2S	36%	40%
Positive for FC	23%	35%
> 10 CFU/100ml FC	3%	18%
> 20 CFU/100ml FC	0%	18%
> 200 CFU/100ml FC	0%	12%

Low Level Microbial Contamination

Causes of Waterborne Disease?

Household Water Storage Practices

Limited Knowledge about Hygiene and Sanitation

Lack of Sanitation Infrastructure

Use of Private Tubewells, Open Wells, and Open Water Sources

Lumbini Pilot Studies - Timeline

Jan. 2001
Chlorination Program Setup

Feb. 2001- Dec. 2001
Monitoring of Chlorination Program

Dec 2001-Jan. 2002
Biosand Filter Installation

Jan. 2002
Chlorine Program Evaluation

Household Chlorination Pilot Study

Jan. 2001 – Jan. 2002

GOALS

- Provide Safe Water to a portion of the Lumbini population
- Test the acceptance of household chlorination in Nepal

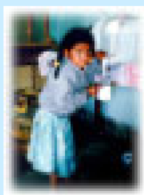
Based on CDC Safe Water Systems

www.cdc.gov/safewater

The Safe Water System Approach

- **Point-of-Use Treatment** using locally produced and distributed sodium hypochlorite solution.

•**Safe Water Storage** in plastic containers with narrow mouths, secure lids and dispensing spigots to prevent recontamination.



•**Behavior Change Techniques** to influence hygiene behaviors and increase awareness about the dangers of contaminated water and waterborne disease.

Biosand Filter

Slow sand filtration principles

- Made of local materials
- Key biological removal
- No chemical additives
- Easy to clean

Dr. David Manz, U of Calgary design

- Intermittent household use
- Relatively fast flow rate
- Economically sustainable

Key Components for Program Success

Relevant Goals - Measurable Indicators

Overall Goals of a SWS Program (CDC)

-Improve water quality in homes by means of a sustainable technology

-Reduce death and diarrhea from contaminated drinking water

-Improve hygienic behaviors related to water use

Objectives of Lumbini Pilot Study

-Greater than 30% reduction in *waterborne disease* among participants

-Less than 10% of chlorinated stored water testing positive for *bacterial contamination*.

-Less than 10% of sample group participants reporting complaints about the *taste of chlorinated water*.

Biosand Program ?

Use of Existing Organizations

Environment and Public Health Organization

Kathmandu, Nepal

International Buddhist Society

Lumbini, Nepal

Health Motivators

Women Empowerment Committees

Village Development Committees

Inclusion

User Groups

Women

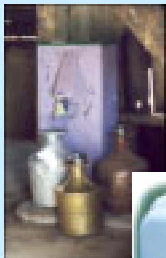
Children

Schools

Education

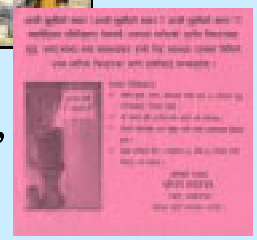
Project Promotion

“Hardware”



vs.

“Software”



“We are convinced that this project succeeded only because it concentrated on people: on one hand people transferring knowledge, and on the other, people absorbing this knowledge and learning to use it to their advantage.”

- Minister of Natural Resources
  Guinea - Bissau

Biosand Pilot Study

- Laboratory results
  – 100% protozoan cyst removal
  – 99.9% virus removal
  – 99.5% bacteria removal (Lee, ’01 MIT M.Eng)
- Field studies
  – 60-99% bacterial removal
- Solution:
  – Design technology to minimize site specific “software” issues
  – Address persisting “software” issues

Expansion of Pilot Programs

Respond to Demand / Expand Program Reach

Cost Recovery / Sustainability

Address Sanitation & Hygiene

Massachusetts Institute of Technology

Civil and Environmental Department

Sodium Hypochlorite Generation

by Luca Morganti

The Objective

PRODUCE A CHLORINE DISINFECTANT

&

ESTABLISH MICRO-ENTERPRISE PROGRAM

Piyush

Imported bleaching powder

↓

Sodium hypochlorite

on-site generation

Why on-site generation ?

Suggestions from Nadine Van Zyl, M.Eng. 2001

- Flexible & easy process
- Adequate capacity (25,000 ca./d)
- No solid waste
- Cheaper (hopefully!)

DONATION

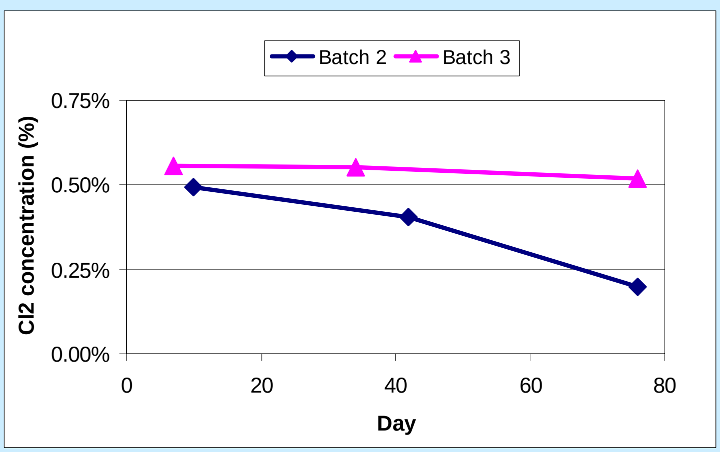
↓

IMPLEMENTATION

Technical challenges

- Set-up equipment
- Procuring material
- Training personnel
- Testing
  - »Cycle duration √
  - »Amount of salt √
  - »Consistency between batches √
  - »Consistency between bottles √
  - »Stability of the product ×

Sodium hypochlorite decay



Factors affecting stability: light, heat, IRON

The Explanation

January 11th – Production of batch 2
....
January 15th – Replacement of the spigot
January 16th – Production of batch 3

Economical Aspects

Logical framework

- Analysis of the production process
- Assessment of production cost
- Comparative analysis of the product
- Quality control procedures
- Target market and clients
- Micro-enterprise structure
- Distribution channels
- Promotion strategies

Tools for Business Management
(Excel spreadsheet)

Production : 4.0 NRs/L (US$ 0.20/gal) with generation
vs. 6.4 NRs/L (US$ 0.32/gal) with powder

Conclusions

- On-site sodium hypochlorite generation is technically feasible in Nepal
- A generator has been installed & tested, and is currently operated by ENPHO
- ENPHO has been provided with both technical and economical recommendations, which will allow it to run SUSTAINABLY a micro-enterprise for sodium hypochlorite production and promotion

Massachusetts Institute of Technology
Civil and Environmental Department

Arsenic Remediation

by Tommy Ngai
Barika Poole
Jeff Hwang

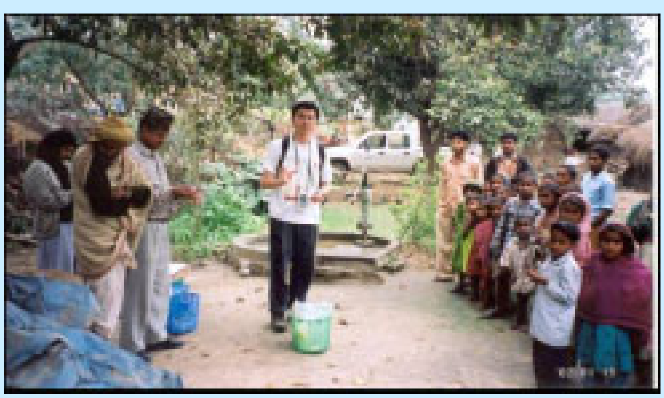
Arsenic background

- Source: natural
- Toxicology:
  - poison
  - causes skin disease, pigmentation, kidney problems, cancer
- WHO guideline: 10 μg/L total arsenic
- Nepali guideline: 50 μg/L total arsenic
- Nawalparasi district: 27% over 10 μg/L

Field work in Nepal

Two main parts:

1. Arsenic speciation
2. Arsenic removal technology evaluation



Speciation

Reasons:

- As(III) more toxic and mobile than As(V)
- As(III) more difficult to treat

Results:

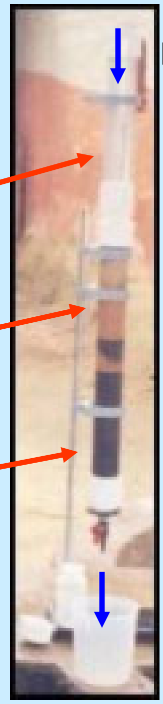
- Visited over 50 wells
- As(III) average 79% (range: 47%-100%)
- Strong correlation with Oxidation-Reduction Potential
- No correlation with well depth, age, usage

Arsenic Remediation Technology

Purpose:

- Evaluate the effectiveness of the Benzyl Pyrindium Iodide (BP/I_3) & Alumina Manganese Oxide (A/M) media

Setup



Arsenic Removal Results

Raw water	Total arsenic	A/M only	A/M & BP/I3
1. Parasi, Nawalparasi	242 ppb	0 ppb	0 ppb
2. Parasi, Nawalparasi	152 ppb	0 ppb	0 ppb
3. Parasi, Nawalparasi	320 ppb	0 ppb	0 ppb
4. Parasi, Nawalparasi	280 ppb	0 ppb	0 ppb
5. Madangram, Devdaha	800 ppb	N/A	0 ppb
6. Madangram, Devdaha	200 ppb	N/A	0 ppb
7. Madangram, Devdaha	150 ppb	N/A	0 ppb
8. Sunwal, Nawalparasi	350 ppb	N/A	0 ppb
9. Sunwal, Nawalparasi	200 ppb	N/A	0 ppb

Cost for A/M media ~ $US 5 /household/year
Availability of media is a problem

Household Arsenic Removal Technology

- Objectives:
  - Evaluate efficiency of ENPHO Arsenic Removal System
  - Come up with possible improvement(s) that can be implemented
- Background on ENPHO Arsenic Removal System
  - Adopted from a Bangladesh Design
  - Coagulation/coprecipitation used as removal mechanism
  - 1,000 filters currently being distributed to people with immediate needs as a pilot program

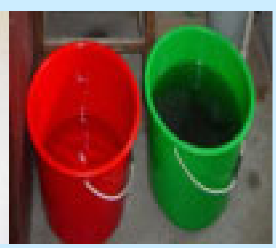
ENPHO Arsenic Removal System

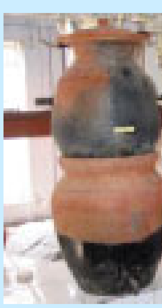
- Chemicals:

  Ferric Chloride – coagulant

  Hypochlorite – oxidant

  Charcoal – adsorbent





- Filter

  Locally manufactured ceramic

  High porosity

Arsenic Removal Mechanisms

Chemical Addition & Settling:

1. Oxidation of As(III) to As(V)

2. Precipitation of Ferric Hydroxide:
   $FeCl_3 + 3H_2O \rightarrow Fe(OH)_3\ (s) + 3Cl^- + 3H^+$

3. Coprecipitation:
   $Fe(OH)_3 + H_2AsO_4^- \rightarrow$ Fe-As Complex

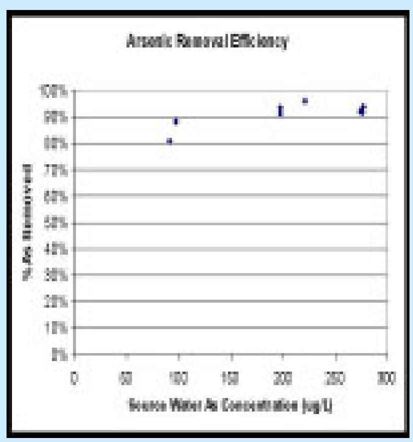
4. Settlement

Filtration

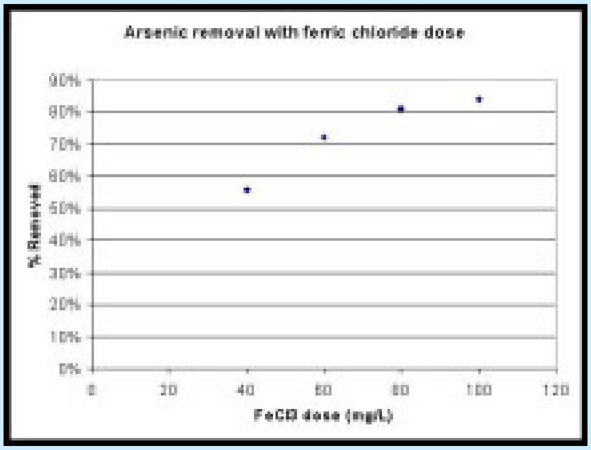
Test Results From Nepal

- Good removal rate observed
  - 100 to 300 ug/L = source water As concentrations
  - 10 to 20 ug/L = all treated samples

- Microbial Test Result:
  - Fecal Coliform reduced by 99%

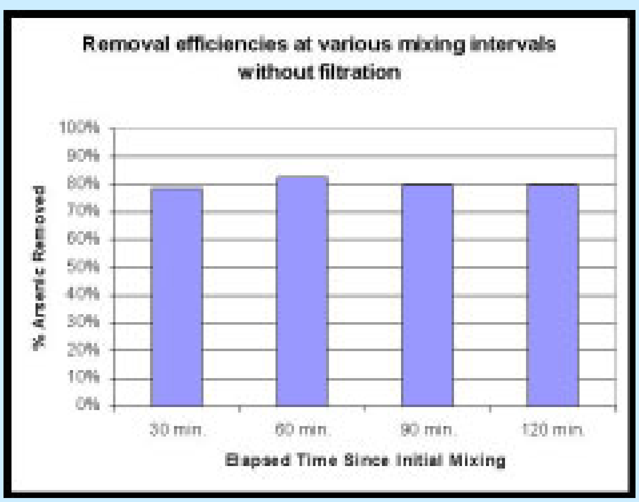


Coagulant Dosage



Note: Results obtained without filtration

Mixing/Settling Regime Study



Summary

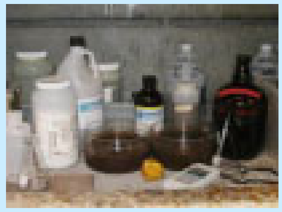
- Current ENPHO Arsenic Removal System was successful in reducing As below “Interim Nepali Standard” 50 ug/L
- Very good fecal coliform removal
- Social acceptability is an unanswered question
  – Can be improved with only one time mixing and shorter settling time

Iron Oxide Coated Sand

- Remove arsenic from groundwater below Nepali Interim Standard of 50ppb and WHO guideline of 10ppb
- Appropriateness for Nepal
  -Local fabrication
  -Cost
- Social Acceptability
  -Ease of Use

Iron Oxide Sand Preparation

Precipitation of iron oxide from ferric nitrate and sodium hydroxide solution



Mix with colloids and bake for 10-20 hours

Acid wash sand for 24 hrs.
Dry in oven

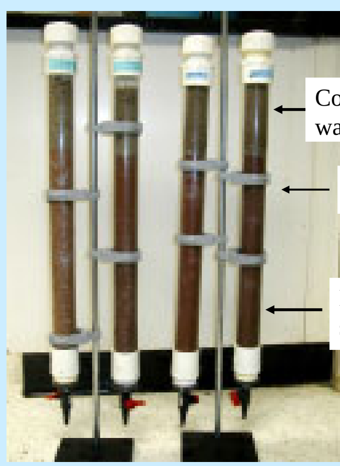
Seven different sands prepared varying colloidal solution and drying temperature

Field Testing

- Sands tested in Pepperell, MA, Parasi, Nepal, Bow, NH

Possible rxns of arsenate with hydrous iron oxide

- $Fe(OH)_3\,(s) + H_3AsO_4 \rightarrow FeAsO_4 + H_2O$
- $[FeOH°] + AsO4^{3-} + 3H+ \rightarrow [FeH_2AsO_4] + H_2O$
- $[FeOH°] + AsO4^{3-} + 2H+ \rightarrow [FeHAsO_4\text{-}] + H_2O$



Results

IOCS	Drying Temp.	% Removal As conc. 95-300 µg/L
1	~170-200ºC 10 hrs	68-100%
2	Held at 120ºC for 9hr, then ramped to 550ºC for 6hrs.	21-54%
3	Held at 100-110ºC overnight then ramped to 550ºC held for 12 hrs.	N/A
4	~ 110-150ºC for 17 hrs	33-69%
5	~ 110-150ºC for 17 hrs	95-100%
6	550ºC for 15 hrs	N/A
7	550ºC for 15 hrs	N/A

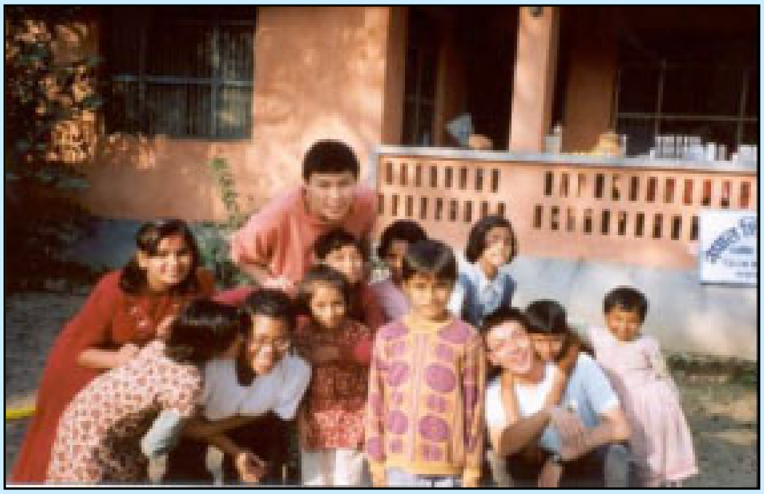
Fabrication Costs

Media	Required Amount	Unit Cost	Cost/200mL sand
Ferric Nitrate	52.1g/200mL sand	62.5NRs/500g	6.5NRs
HCL	66mL/200mL sand	15NRs/L	0.99NRs
Sodium Hydroxide	38.4g/200mL sand	17.5NRs/500g	1.34NRs
Total			**8.83NRs (USD 0.12)**

Total media ~7L= USD 4.26
Bucket = USD 1

Total Cost ~ 5.26

Our Assistants in Parasi



Massachusetts Institute of Technology

Civil and Environmental Department

Tubewell Program

by Xuan Gao

Tubewell

- A well equipped with a handpump
  - Concrete Platform
  - Drainage Channel

Tubewell

- Common in Nepal
- Advantages over traditional water sources
- Microbial contamination of tubewell water
- Project goals:
  - Determine the causes of contamination
  - Develop measures to eliminate the contamination
  - Develop a maintenance program for tubewells

H_2S Bacteria Test

- Water quality testing using H_2S bacteria P/A test

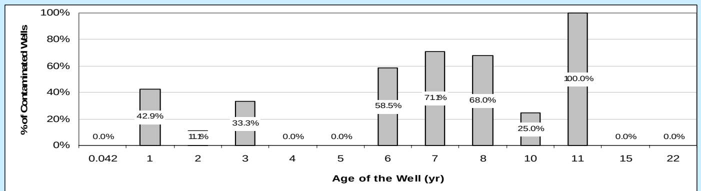
- 42% of the wells were contaminated with H_2S bacteria

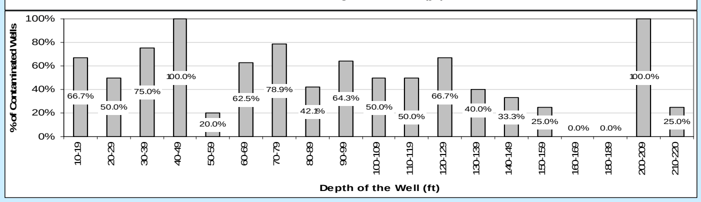
Causes of Contamination

- Depth of the wells
- Age of the wells
- Number of users per well
- Distance to the nearby latrine
- Distance to the nearby animal shed
- Use of cow dung as slurry in the construction of tubewells

Causes of Contamination (cont.)

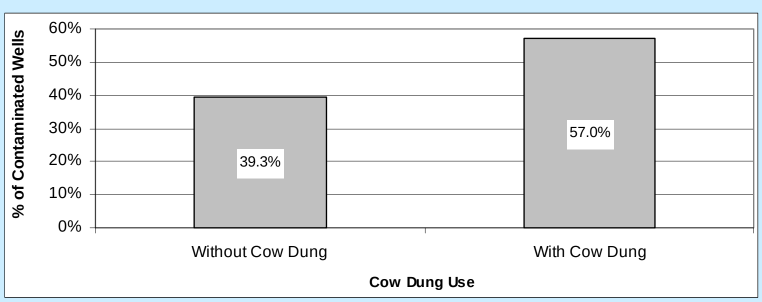
First 5 factors are unlikely to be the causes of the microbial contamination





Use of Cow Dung

- 17.8% increase in percentage of contaminated wells from "without cow dung" to "with cow dung"
- Use of cow dung may be one of the causes of the contamination



Shock Chlorination

- One-time introduction of a strong chlorine solution into a well
- Need to be carried out periodically

Other Possible Causes

- Broken Platforms
- Broken Handpump
- Use of dirty water to prime the well
- Flooding during monsoon.

Maintenance Program

- Training of tubewell mechanics
- Women involvement
- Regular water quality monitoring
- Shock chlorination
- Health and hygiene education
- Regular meeting of users

Some Thoughts

- Users need to develop a sense of ownership of the wells
- Education is the most important!!!

More information

For more information:

http://ceeserver3.mit.edu/~Nepal

Acknowledgments

- Susan E. Murcott
- Dr. Eric Adams
- Amy Smith
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- ENPHO
- DIDC (former FINNIDA)
- IBS
- Department of Material Science, MIT
- Parsons Lab
- All the M.ENGers!