Findings on Arsenic Mitigation Technologies Testing and Evaluation in Nepal

Workshop on the Role of Environmental Performance Verification for Safe Water in Nepal

November 30th & December 1st, 2006

Kathmandu, Nepal

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Presentation Topics

1. MIT Nepal Water Project
2. Arsenic Technologies Testing
3. Kanchan Arsenic Filter
4. Project status
5. Lessons and Conclusions

MIT Nepal Water Project (since 1999)

Objective:

- To research, develop, and implement appropriate household-level water treatment (HWT) technologies

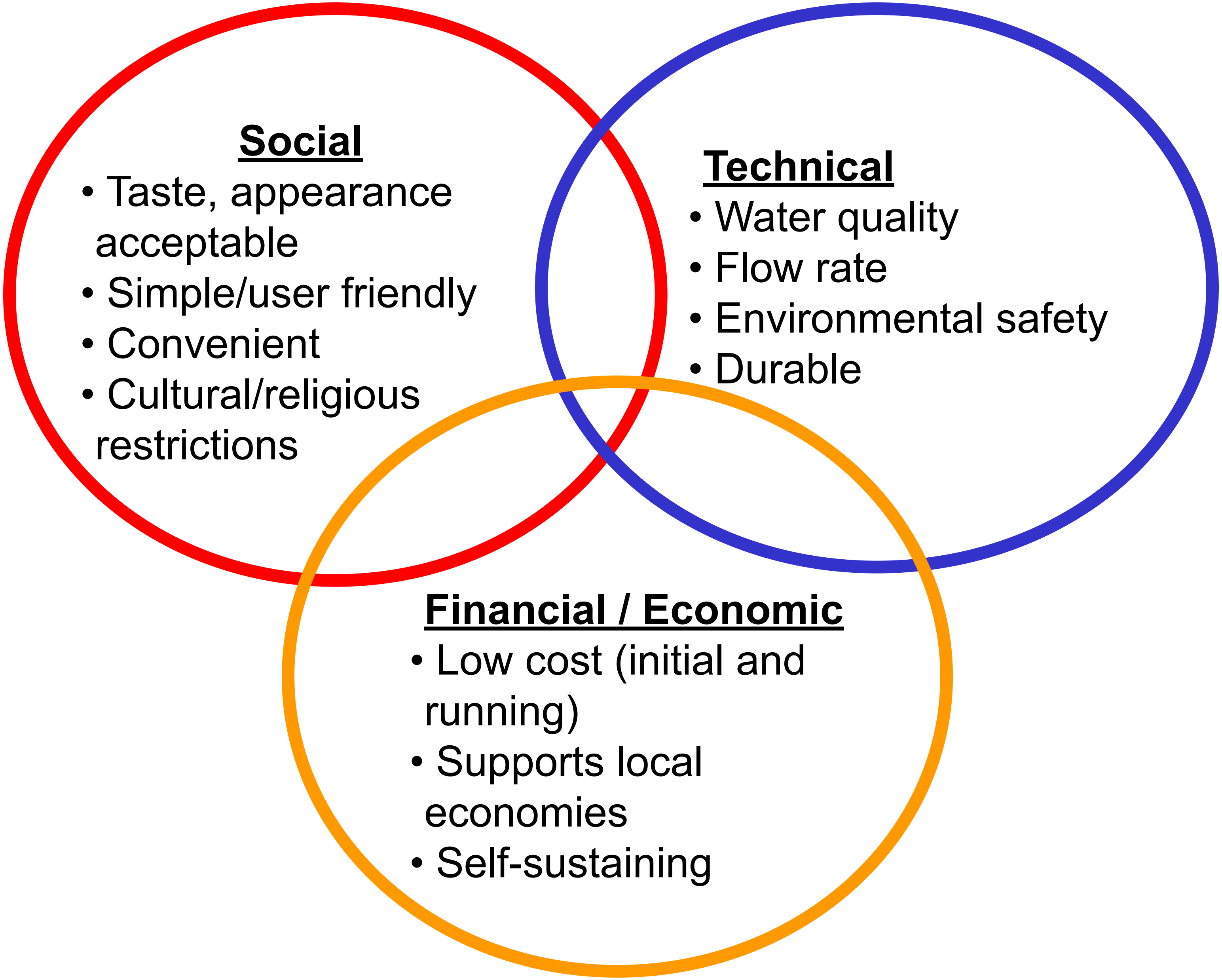
Arsenic is a Major Component:

- 15 out of 40 students and faculty came to Nepal to study arsenic

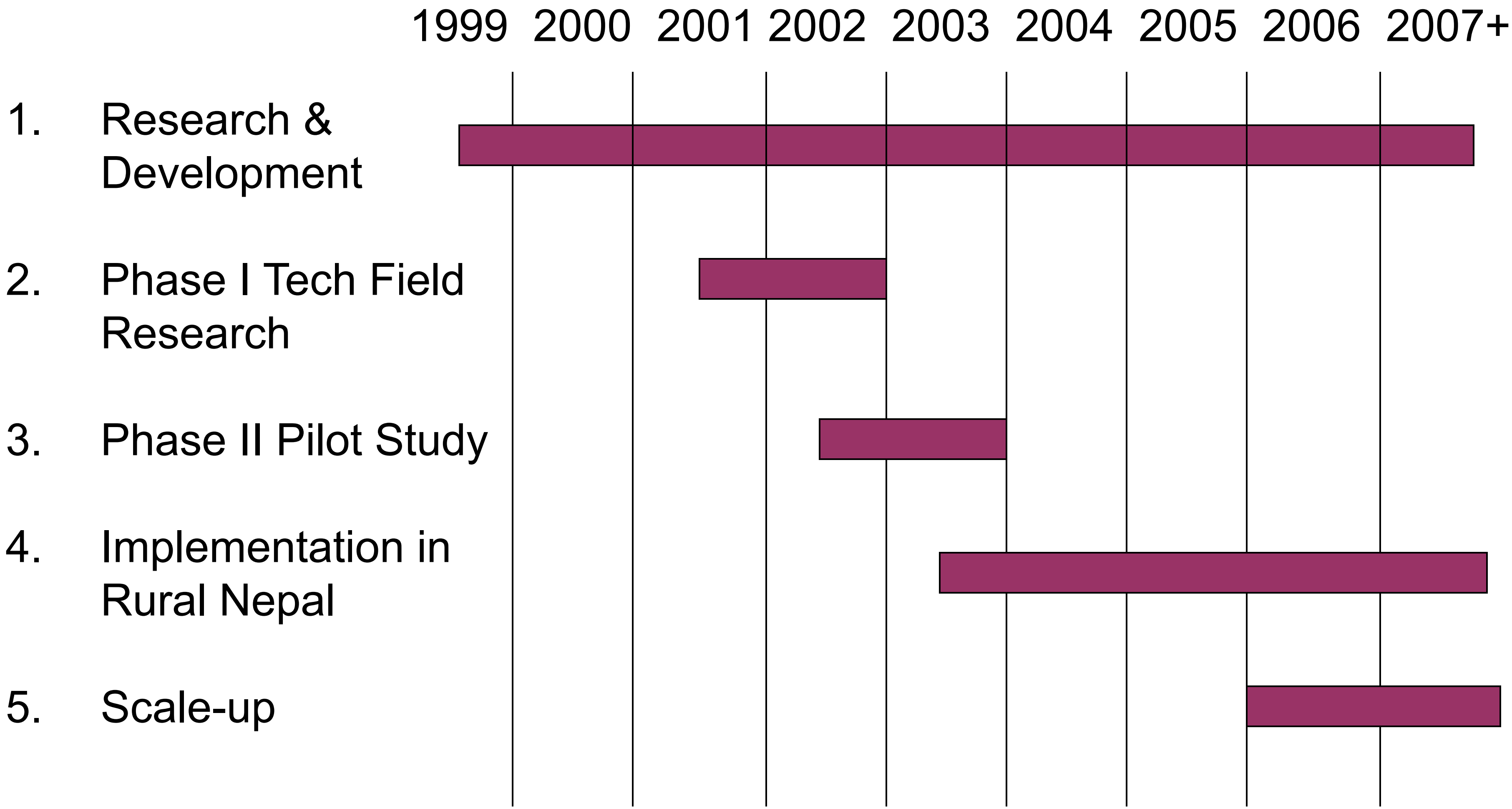
Key Partners in Arsenic Research

- Environment and Public Health Organization (ENPHO)
- Rural Water Supply and Sanitation Support Program (RWSSSP)

Design for Sustainable Development



Project Timeline



Step 1 – Research and Development

Research on various mitigation options

Arsenic Mitigation

Alternative Arsenic-Free Sources

- Safe tube wells
- Improved Dug wells
- Deep wells
- Rainwater harvesting
- Surface water treatment

Arsenic Removal Technologies

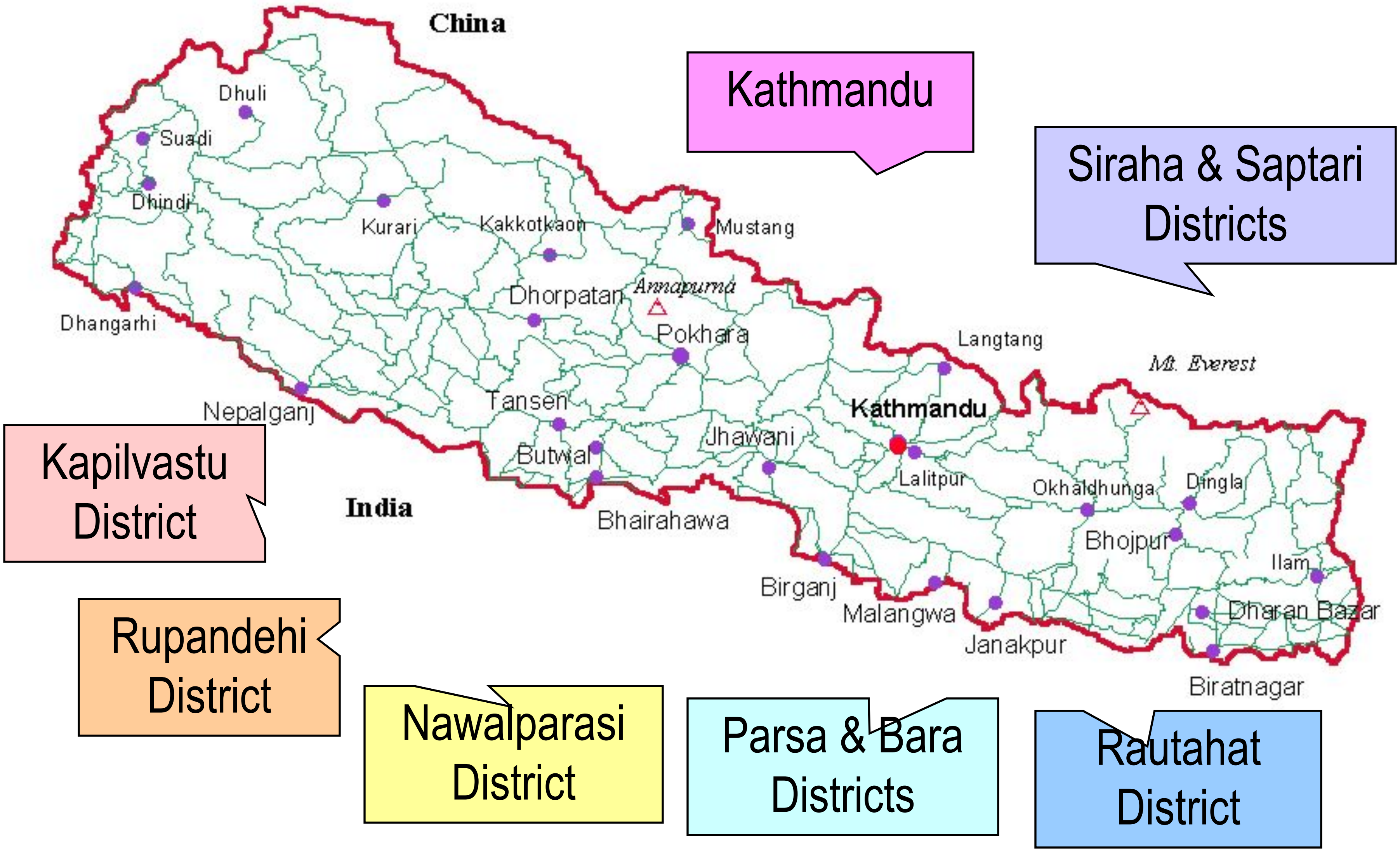
- Aeration/Oxidation
- Coagulation/Precipitation
- Adsorption
- Ion-Exchange
- Membrane

Collected information for 50+ technologies in our database

http://web.mit.edu/murcott/www/arsenic

Step 1 – Research and Development

Site Assessment



Step 2 – Phase I Field Study
Field Experiments

Screened 8 technologies from database to be field tested against following criteria:

1. Technical Performance
2. Social Acceptability
3. Low cost

3 – Kolshi/ Gagri

Source:
Hurd, J. (2001). *Evaluation of three Arsenic Removal Technologies in Nepal*. MIT Master of Engineering Thesis. June 2001

Iron filings
Coarse sand

Fine sand

Collection

Results:

Arsenic Removal = 97%

Flow rate 4 L/hr and decreasing

Cost about US$10

Iron filings not easily found

Jerry Can

Source:
Hurd, J. (2001). *Evaluation of three Arsenic Removal Technologies in Nepal*. MIT Master of Engineering Thesis. June 2001

Results:

Arsenic Removal = 0%
(does not work!)

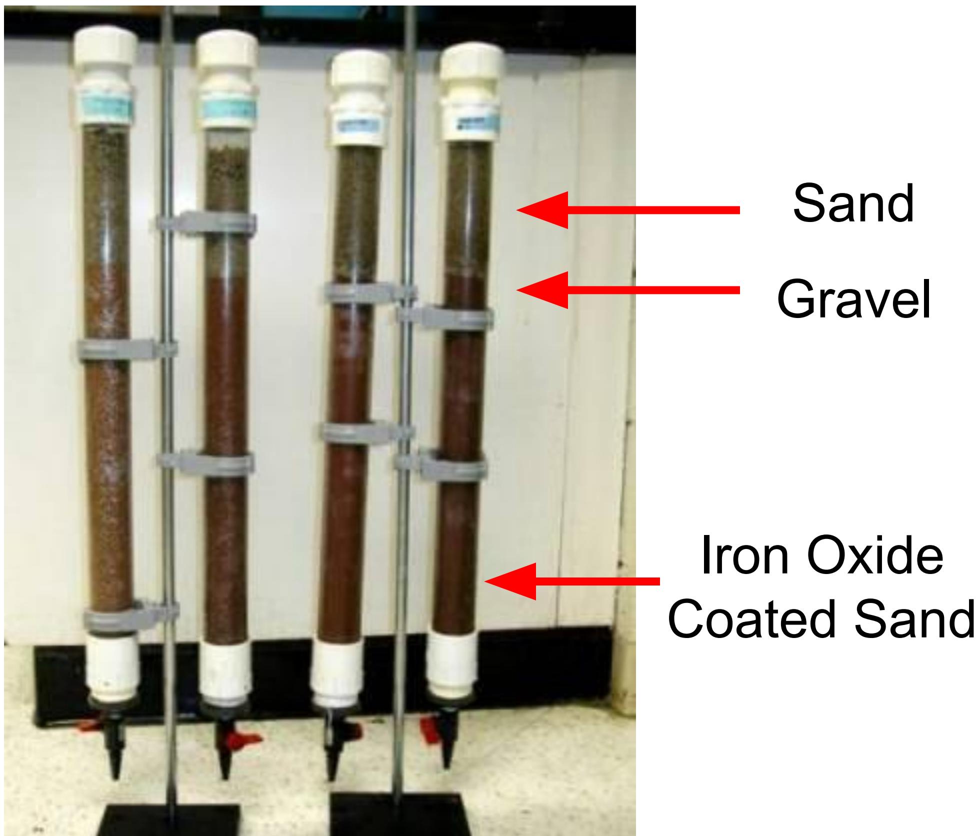
Cost about US$1

Iron filings not easily found

Iron filings

Iron Oxide Coated Sand (IOCS)

Source:
Poole, B (2002) *Point-of-use Water Treatment for Arsenic Removal Through Iron Oxide Coated Sand: Application for the Terai Region of Nepal*. MIT Master of Engineering Thesis. June 2002



Results:

Arsenic Removal = 90%

High flow rate, 20 L/hr

Cost about US$10-15

Complicated production process

Activated Alumina (Apyron Aqua-Bind)

Source:
Hurd, J. (2001). *Evaluation of three Arsenic Removal Technologies in Nepal*. MIT Master of Engineering Thesis. June 2001

Results:

Arsenic Removal = 98%

High flow rate, 800 L/hr

Cost about US$2000 initial, $300 replacement media

Only available in USA, no sales and support in Nepal

Need backwashing

Chlorine tablet

Alumina media

GAC

Activated Alumina (Aquatic Treatment Systems)

Oxidation media

Alumina media

Source:

Ngai, T (2002). *Arsenic Speciation and Evaluation of an Adsorption media in Rupandehi and Nawalparasi Districts of Nepal*. MIT Master of Engineering Thesis. June 2002

Results:

Arsenic Removal = 97%

High flow rate, 20 L/hr

Cost about US$20-30 initial

Only available in USA, but no sales and support in Nepal

Need backwashing

Coagulation Precipitation (2-Kolshi)

Source:
Hwang, S.K. (2002). *Point-of-Use Arsenic Removal from Drinking Water in Nepal Using Coagulation and Filtration.* MIT Master of Engineering Thesis. June 2002

Chemical packet :
- Ferric chloride
- Sodium hypochlorite
- Charcoal powder

Results:

Arsenic removal = 91%

Low treatment rate, 3-5 L/hr

Cost about US$10 initial, chemical $10/ year

Chemical prepared by ENPHO

Arsenic Iron Removal Plant (AIRP)

Source:
Poole, B (2002) *Point-of-use Water Treatment for Arsenic Removal Through Iron Oxide Coated Sand: Application for the Terai Region of Nepal*. MIT Master of Engineering Thesis. June 2002

Results:

Arsenic removal = 5 to 88%, depending on influent iron

Cost about US$300 initial

Lack of maintenance, not in operation

Kanchan Arsenic Filter (KAF)

Source:

Ngai, T., Walewijk, S. (2003). *Arsenic Biosand Filter (ABF) Project: Design of an Appropriate Household Drinking Water Filter for Rural Nepal.* Final Report. Massachusetts Institute of Technology. July 2003.

Results:

Arsenic removal = 90%

Good iron and microbial removal

High flow rate = 30 L/hr

Cost about US$30

Step 2 – Phase I Filter Study

Summary Results

Technology	Technical	Social	Cost	Recommend for Phase II?
3-Kolshi	✓	✓	✓	✓
Jerry Can	✗	✗	✓	✗
Iron Coated Sand	✓	✗	✓	✗
Alumina #1	✓	✗	✗	✗
Alumina #2	✓	✗	✓	✗
2-Kolshi	✓	✓	✓	✓
AIRP	✗	✗	✓	✗
KAF	✓	✓	✓	✓

Step 3 – Phase II Pilot Study

3 Kolshi

15 filters in 2 Kapilvastu villages over 6 months

2-Kolshi

100 filters in Nawalparasi and Rautahat over 12 months

Kanchan Arsenic Filter

16 filters in 4 Nawalparasi villages over 6 months

General Observations

1. Coagulation chemicals difficult to obtain in rural Nepal. Setup of a new distribution network is difficult and costly.

2. Similarly, access to imported media (e.g. activated alumina) is difficult.

3. Lack of capability for complicated manufacturing process (e.g. iron-coated sand)

4. Filter constructed by local technicians using locally available materials can promote local employment/economy.

General Observations

5. Colour, taste, turbidity of filtered water are important determinants to the user's acceptance of a technology.

6. Technology must remove microbial contamination

7. Users tend to skip filtration if the filtration rate is too low or operation too inconvenient.

8. Lack of proper maintenance is prevalent for many community-scale systems

Sources:
Tabbal, G. (2003) *Technical and Social Evaluation of Three Arsenic Removal Technologies in Nepal*. MIT Master of Engineering Thesis. June 2003
Ngai, T., Murcott, S., and Shrestha, R. *Kanchan Arsenic Filter (KAF) – Research and Implementation of an Appropriate Drinking Water Solution for Rural Nepal*. Paper to the 9th Forum on Arsenic Contamination of Groundwater in Asia, Asia Arsenic Network and Research Group of Applied Geology. Yokohama, Japan. November 20-21, 2004

Step 3 – Phase II Pilot Study
Summary Results

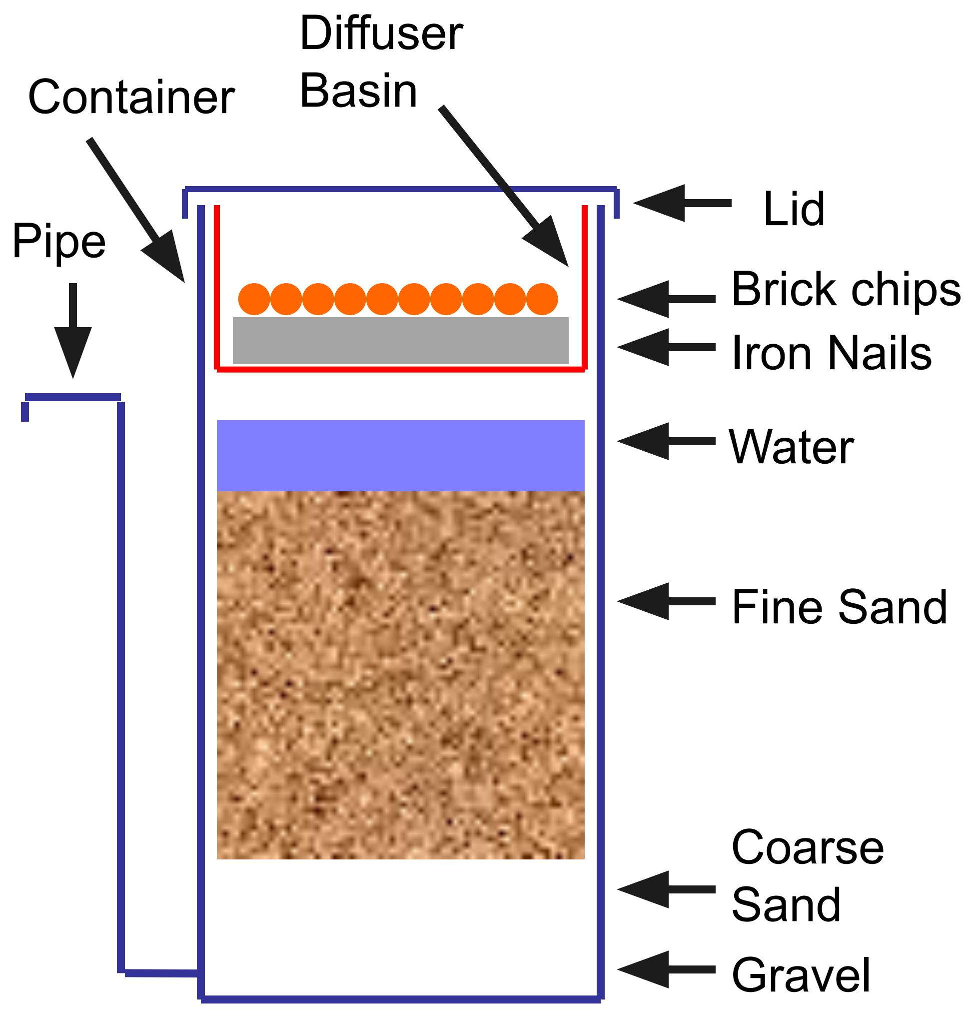
	3-Kolshi	2-Kolshi	KAF
Arsenic removal	★★★	★★	★★★
Microbial removal	★	★★★	★★
Flow rate	★	★	★★★
Easy construction	★★★	★★★	★★★
Simple O&M	★★	★★	★★★
Minimal environmental impact	★★	★★	★★
Material availability	★★★	★	★★★
User acceptance	★★	★	★★★
Low initial cost	★★★	★★★	★★
Low running cost	★★	★★	★★★
Overall Ranking	2nd	3rd	Best

★ = poor ★★ = moderate ★★★ = good

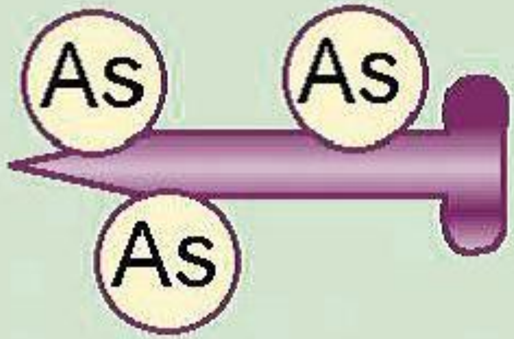
Kanchan™ Arsenic Filter, KAF
(formerly Arsenic Biosand Filter)

- Developed by MIT and ENPHO
- Open-source technology
- Based on arsenic adsorption on rusty iron nails and microbial removal by slow sand filtration
- Removal of arsenic, bacteria, iron, turbidity, and odour
- Require no external energy/material input for operation
- Constructed by local technicians using local materials
- Environmentally safe disposal

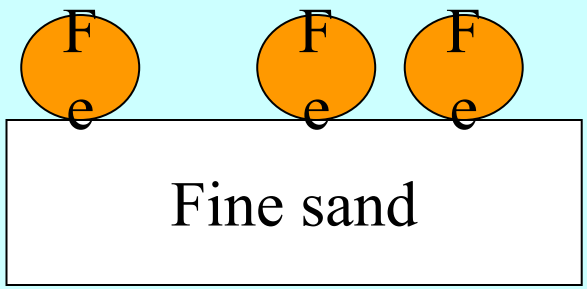
KAF Components and Principles



Arsenic and Iron Removal Mechanisms



Arsenic (As) particles are effectively adsorbed on the rusted iron nails surface.

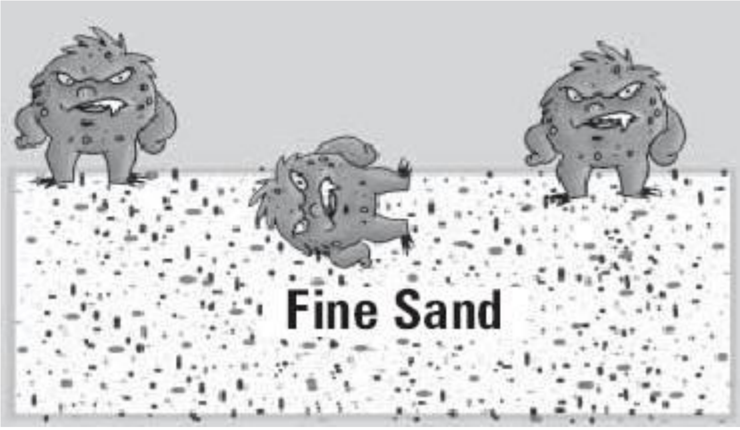


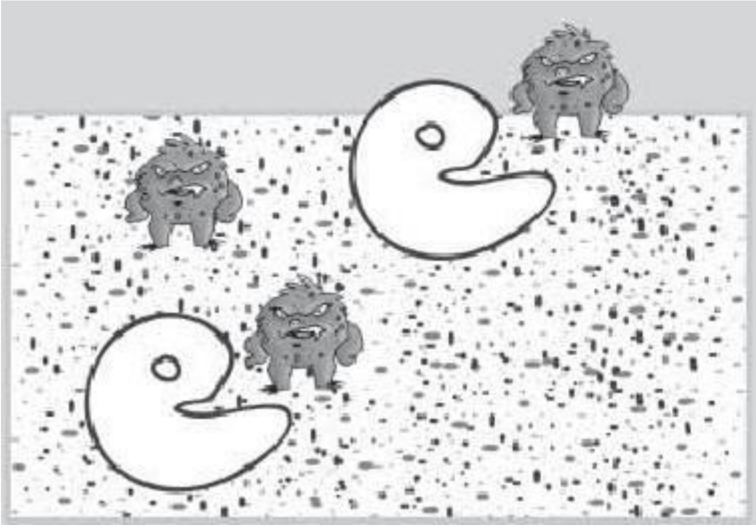
Iron particles are trapped on top of the fine sand layer by physical straining (i.e. too large to pass)

Pathogens Removal Mechanism

Pathogens are removed by 4 main mechanisms:

1. Straining
2. Attachment
3. Predation
4. Natural die off





KAF Versions

We have developed 4 different versions of the KAF, each with its own advantages and limitations

Concrete Square

Concrete Round

Plastic Hilltake

Plastic Gem505

Cost Breakdown (Gem505 version)

	Cost (Nov 06)	
Item	NRs	$US
Container, basin & lid	452	6.28
Piping system	205	2.85
Sand & gravel	40	0.56
Iron Nails	365	5.07
Bricks	6	0.08
Chlorine solution	35	0.49
Tools, bags	15	0.21
Printed manual	10	0.14
Transportation	60	0.83
Labour	80	1.11
Subtotal	**1268**	**17.61**
Profit 10%	127	1.76
Selling price	**1395**	**19.37**

Tommy Ngai Pilot Study

Source:
Ngai, T., Walewijk, S. (2003). *Arsenic Biosand Filter (ABF) Project: Design of an Appropriate Household Drinking Water Filter for Rural Nepal.* Final Report. Massachusetts Institute of Technology. July 2003.

Experiment:
16 filters in 4 Nawalparasi villages over 3 months

Results:

Arsenic removal	87-96%
Iron removal	90-99%
Total coliform removal	60-100%
Flow rate	14 L/hr average

Naomi Odell Study

Source:
Odell, N. (2004). *Report on a Four-Month Performance Evaluation of the Cement Arsenic Biosand Filter (ABF) for Mitigation of Arsenic Contamination*. US Peace Corp Volunteer. April 2004

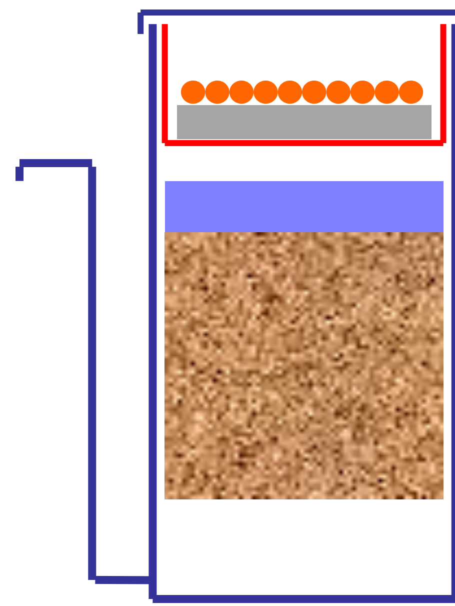
Experiment:
Two filters in Parasi over 4 months

Results:
Arsenic removal 95%
No media exhaustion observed

Shashank Pandey Study

Source:
Pandey, S. (2004). *Arsenic Biosand Filter: Study on the Effect of Air Space between the Resting Water and the Diffuser Basin on Arsenic Removal and Determination of General Flow Curve*. BSc Thesis. Kathmandu University.

Experiment:
Four filters in Tilakpur, Nawalparasi



Results:

1. No oscillation in filtered water arsenic
2. Arsenic removal takes place at two locations
   - Adsorption on iron nails in the diffuser box
   - Adsorption on iron particles accumulated on top of the find sand

Prem Krishna Shrestha Study

Source:
Shrestha, P. (2004). *Arsenic, Iron and Coliforms Removal Efficiency of Household Level Biosand Filters*. MSc Thesis. Tribhuvan University, Nepal.

Experimental Design:
Lab study in Kathmandu
Field study in Sunwal, Nawalparasi

Results:
1st Phase: Lab study, 1200L, 31 ppm PO4
  Arsenic removal <50%
2nd Phase: Lab study, 1800L, 0.4 ppm PO4
  Arsenic removal 85%
  Total coliform removal 94%
3rd Phase: Field study, 1600L
  Arsenic removal 91%

Dipina Sharma Study

Source:

Sharma, D. (2005). *Kanchan^{TM} Arsenic Filter: Removal of Bacteria (Total Coliforms) of Gem505 Model, 4-weeks Daily Study.* BSc Thesis. Kathmandu University. July 2005.

Experiment:

5 filters in Kasiya, Nawalparasi over 4 weeks

Results:

Total coliform removal >96% for 4/5 filters

Handling and hygiene practices greatly affect microbial removal

Bardan Ghimire Study

Source:
Ghimire, B. (2005). *Kanchan™ Arsenic Filter: Can Iron and Arsenic Particles Migrate through the Sand Layer?* MSc research project. Kathmandu University. July 2005.

Experiment:
- Four filters in Rupendehi

Results:
- Arsenic and iron particles do not migrate over time
- Arsenic and iron particles trapped in the top 4 cm of sand

World Bank DM03 Monitoring

Source:
Ngai, T.K.K., Murcott, S., Shrestha, R.R., Dangol, B., Maharjan, M. (2006) Development and Dissemination of Kanchan^{TM} Arsenic Filter in Rural Nepal. *Water Science & Technology: Water Supply* Vol 6 No 3 pp 137–146 © IWA Publishing

Monitoring Activities

Over 1000 filters from 10 districts monitored in Spring 2004, and again Spring 2005

Measured arsenic, iron, phosphate, pH, flow rate

Also collected information on GPS location, household demography, users feedback…

Arsenic Performance

(all filter version, monitoring Nov04 to Mar05, n=1034)

Effluent Arsenic Concentration (ug/L)

Influent Arsenic Concentration (ug/L)	ND	10	20	30	40	50	60	70	80	90	100	150	200	250	300	350	400	450	500
1000	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0
500	2	2	4	2	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0
450	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	
400	0	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
350	0	2	1	2	1	0	0	0											
300	2	3	1	1	1	0	0	0											
250	7	3	0	0	0	0	0	0											
200	49	11	3	3	1	0	0	0											
150	50	14	5	1	0	1	0	0	0	0	2	1							
100	132	11	3	4	1	0	1	0	0	0	0								
90	91	4	4	3	0	0	0	0	0	0									
80	50	11	1	1	1	0	0	0	0										
70	39	1	0	0	0	0	0	0											
60	42	2	0	1	0	0	0												
50	53	4	1	0	0	0													
40	35	0	0	0	0														
30	52	1	0	0															
20	45	1	0																
10	85	0																	
ND	157																		

Correct installation, operation and maintenance are highly important

Unacceptable
Acceptable

Figure indicates number of filters

Iron Performance
(all filter version, monitoring Nov04 to Mar05, n=1019)

Effluent Iron Concentration (mg/L)

Influent Iron Conc. (mg/L)

	ND	0.1	0.3	0.5	1	2	3	5	10
10	47	0	56	19	41	0	9	0	0
5	37	0	102	9	25	0	1	0	
3	104	0	61	0	2	0	0		
2	16	0	0	0	0	0			
1	219	0	26	0	0				
0.5	3	0	1	0					
0.3	176	1	6						
0.1	0	0							
ND	58								

User Survey Results

(all filter version, monitoring Nov04 to Mar05, n=1074)

Very high compared to other tech

	Everyday	Sometimes	No
Sustained use after 1 year	83%	12%	5%

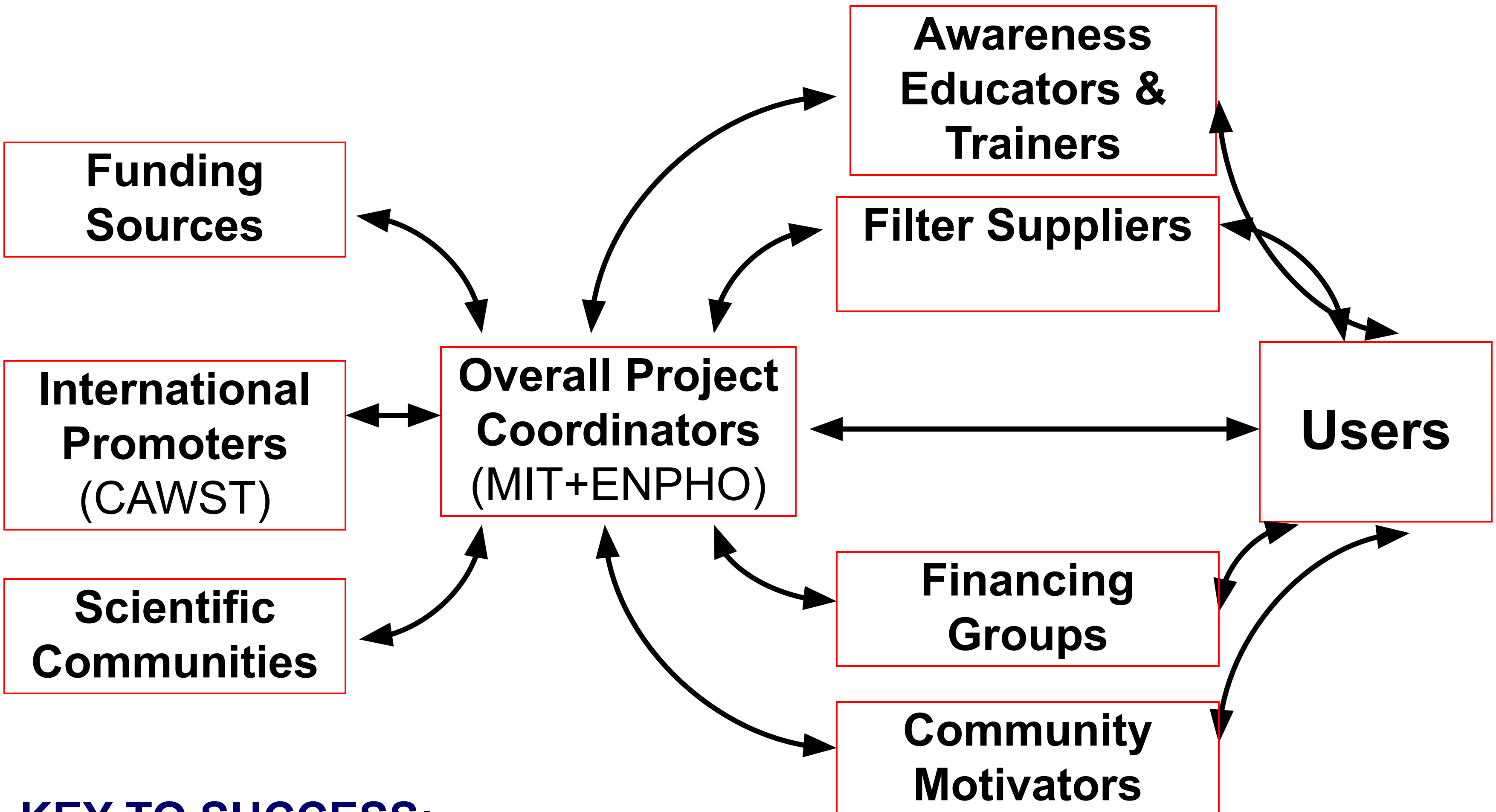
	Better	*Same*	*Worse*
Appearance of filtered water	92.8%	6.9%	0.2%
Taste of filtered water	95.0%	5.0%	0%
Smell of filtered water	88.9%	11.1%	0%
Users' perceived health conditions after drinking filtered water	77.5%	22.5%	0%

	Yes	No
Filter simple to use	87%	13%
Will recommend KAF to other people	85%	15%

KAF Technical Performance – Overall Summary

Parameters	Typical Range
Arsenic Removal	85% to 95%
Iron Removal	93% to 95+%
Coliform Removal	85% to 99+%
Turbidity Removal	80% to 95+%
Flow Rate	15 to 20 L/hour
Iron Nails Media Life	About 3 years

KAF Implementation Model



KEY TO SUCCESS:
Emphasis on self-reliance and long-term sustainability

As of November 2006, about 5000 filters are in operation in Nepal, serving 35,000 to 50,000 people

Awards and Recognition

2002:
- MIT IDEAS Competition, Lemelson International Technology Award, 1st prize, US$10,000

2003:
- World Bank Development Marketplace Global Competition, US$115,000

2005:
- World Bank DM Nepal Country-level Competition, US$20,000
- Wall Street Journal's Technology Innovation Award Competition, Environment Category
- US Environmental Protection Agency, P3 Sustainability Design Competition, US$10,000

2006:
- St. Andrew Prize for the Environment, 2nd place, US$10,000
- Grainger Challenge Competition, finalist
- World Water Forum Kyoto Prize, top 10

Current Research Activities

- Filter redesign to improve quality, performance, acceptability, affordability, and scalability
- Streamline existing implementation model for higher efficiency
- Develop viable business models for filter entrepreneurs

- Explore critical barriers preventing adoption and scale-up
- Test KAF in Cambodia

Lessons and Conclusions

- MIT Nepal Water Project has conducted years of research on arsenic mitigation
- KAF is our best attempt to a sustainable safe water technology so far
- No one-size-fit-all solution, and new techniques being developed, but currently KAF can be a good solution for many parts of Nepal

Lessons and Conclusions

- Need holistic, sustainable development approach
- Excellent technical performance □ Not Enough
- Tech Performance + User Acceptance □ Still Not Enough
- Tech Performance + User Acceptance + Low Cost □ Good, but…
- Arsenic problem is not only about technology, but also about effective implementation, awareness, education, policy, long-term support, sustainability…
- Looking forward for wide collaboration among stakeholders

Acknowledgements

Internationally:

- MIT Civil and Environmental Engineering, USA
- MIT IDEAS Competition, USA
- The Lemelson Foundation, USA
- MIT Sloan School of Business, USA
- The World Bank Development Marketplace, USA
- Sophie Walewijk, USA
- Filters for Families, USA
- Global Water Trust (GWT), USA
- US Geological Survey (USGS)
- US Peace Corps
- US Environmental Protection Agency (EPA)
- Centre for Affordable Water and Sanitation Technology (CAWST), Canada
- Simavi Foundation, Netherlands
- St. Andrews Prize for the Environment, Scotland
- Japanese Red Cross Society (JRCS)
- Hong Kong Polytechnic University
- Rotary International
- UN-Habitat Water for Asian Cities Programme
- WHO HWTS Network
- and many more…

In Nepal:

- Environment and Public Health Organization
- Rural Water Supply and Sanitation Support Programme (RWSSSP)
- National Arsenic Steering Committee (NASC)
- Nepal Red Cross Society (NRCS)
- Department of Water Supply & Sewerage (DWSS)
- Rural Water Supply and Sanitation Fund Development Board (RWSSFDB)
- Department of Education (DOE)
- Department of Irrigation (DOI)
- Nepal Water for Health (NEWAH)
- WaterAid Nepal
- Kathmandu University
- Tribhuvan University
- Kathmandu Rotary Club
- and many more…

Thank You

For more info: http://web.mit.edu/watsan www.enpho.org

EXTRA SLIDES

SUPPORT DATA

Step 2 – Phase I Field Study
Technologies Tested

3-Kolshi

Jerry-Can

Iron-oxide
Coated Sand

Activated Alumina
No.1

Step 2 – Phase I Field Study
Technologies Tested

Activated
Alumina No.2

Coagulation
(2-Kolshi)

Arsenic Iron
Removal Plant

Kanchan Arsenic
Filter

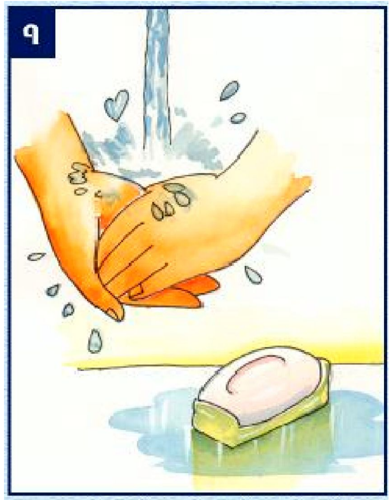
Concrete Square Filter

Concrete Round Filter

Plastic Hilltake Filter

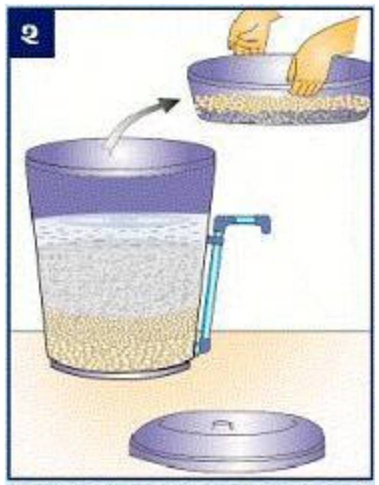
Gem505 Filter

Filter Cleaning/ Maintenance



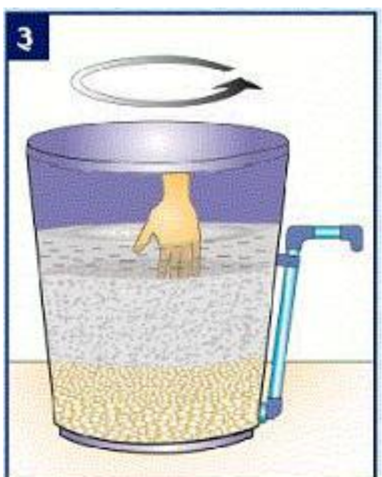
साबुन पानीले हात राम्रो संग धुने ।

1. Wash your hands with soap



किला राखेको बाटा बाहिर निकाल्ने ।

2. Remove diffuser basin

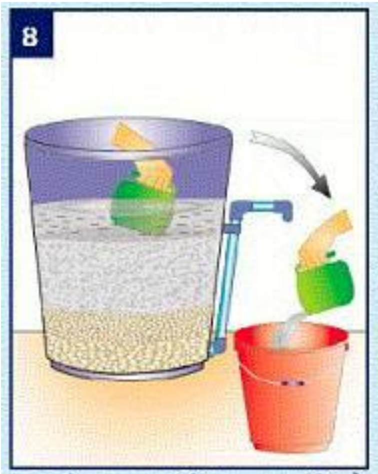


बालुवाको माथिल्लो सतह बाट आधा इन्च जति भित्र सम्म हात छिराएर राम्रो संग बालुवालाई चलाउने ।

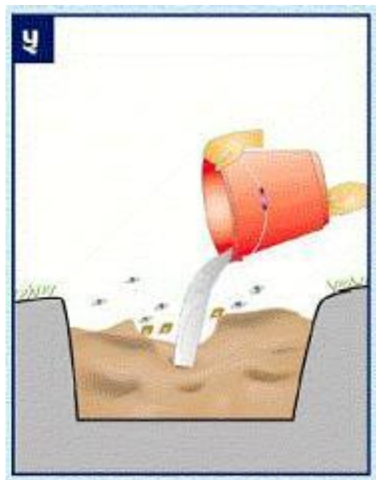
3. Stir the uppermost ½ inch of sand with your fingers

Filter Cleaning/ Maintenance

4a. Remove turbid water with a cup.
4b. Replace the basin and add more water.
4c. Repeat the stirring process for two additional times.

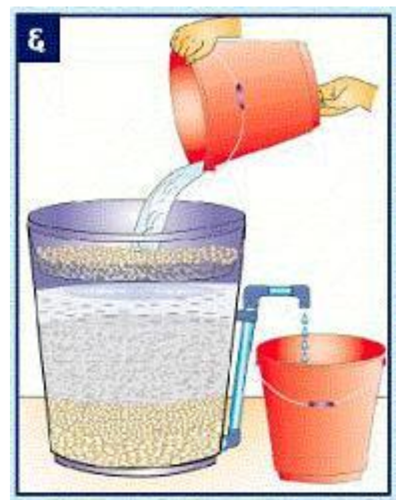


एक छिन चलाएपछि बालुवामाथिको फोहर पानी मगले बाहिर बाल्टिनमा निकाल्ने । पुन: बाटा राखेर पानी खन्याई दुई पटक सम्म यसरी नै सफा गर्ने।



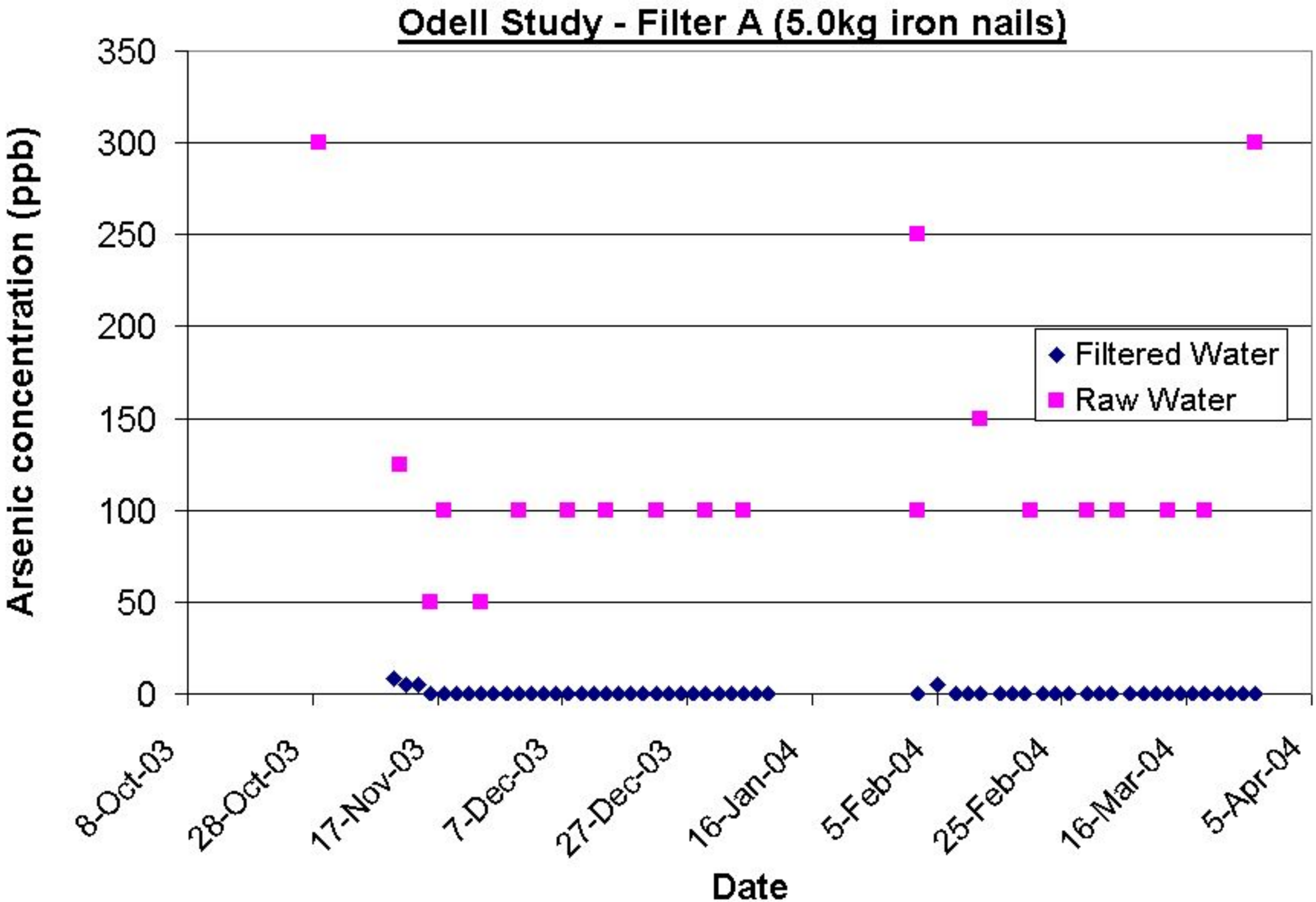
सफा गर्दा निस्केको फोहर पानीलाई खाल्डो खनी थुपारेको गोबरमा फ्याल्ने ।

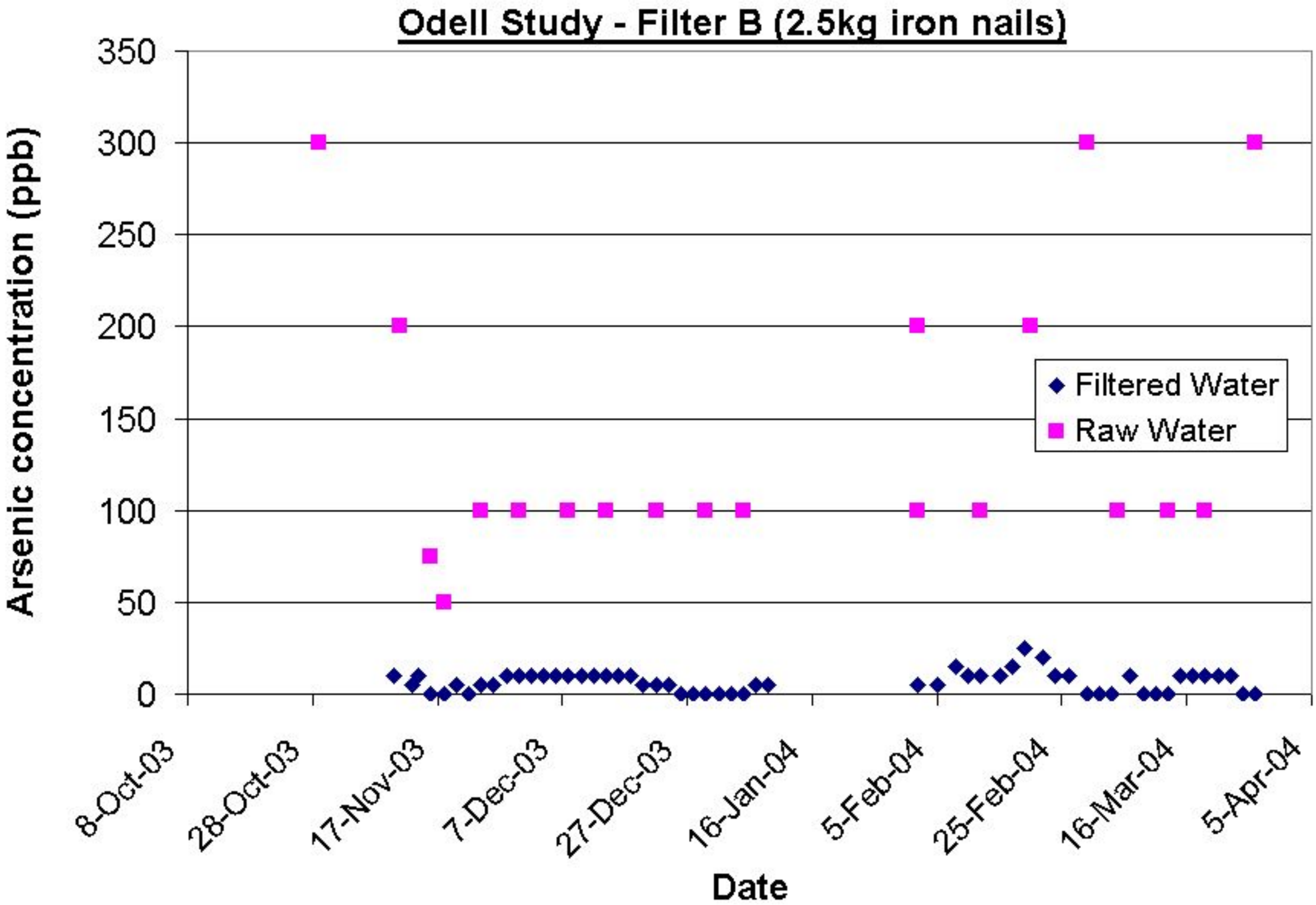
5. Discard the turbid water in a dug hole with some cow dung in it



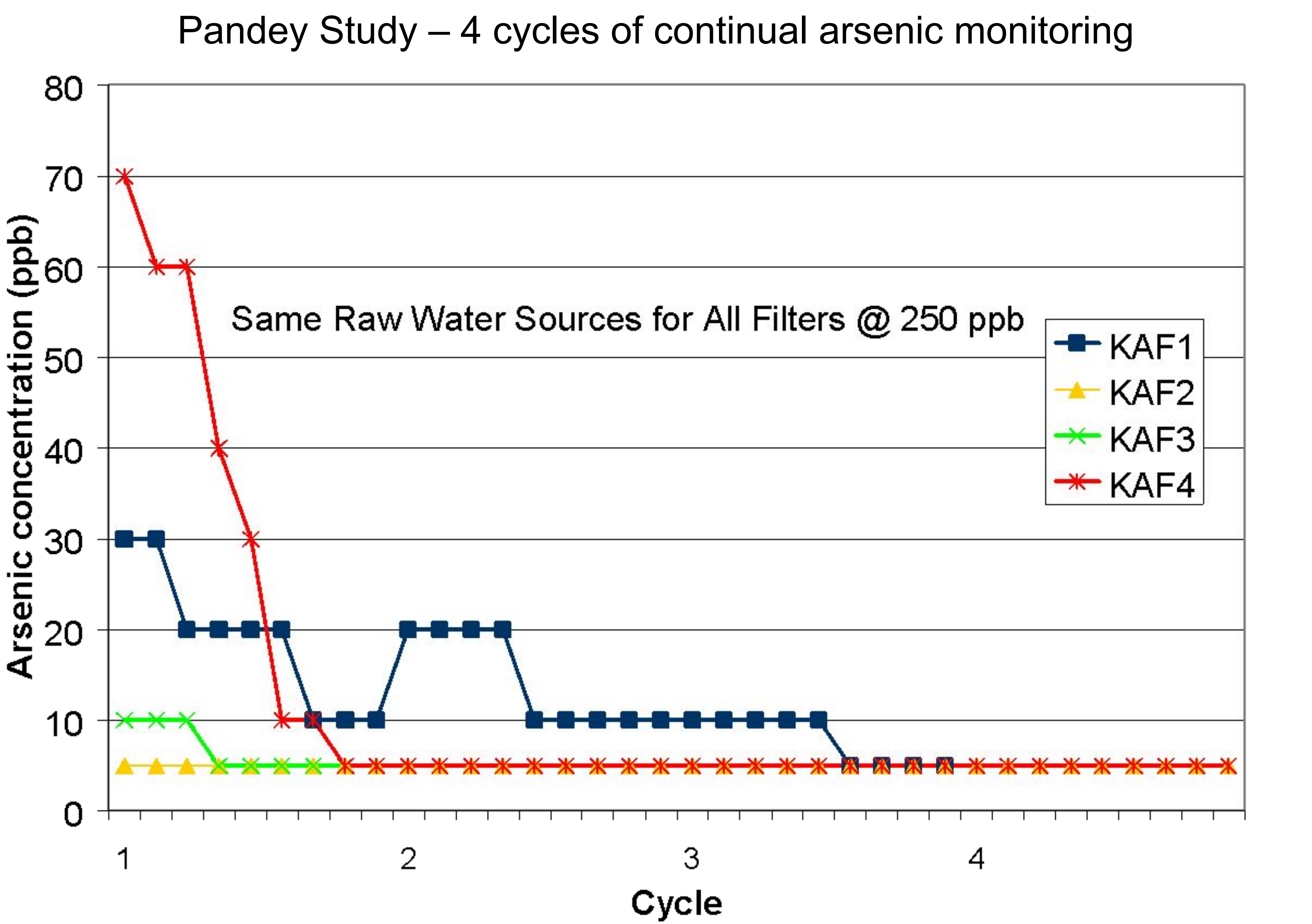
बाटा लाई पहिले जस्तै गरी फिल्टरमा मिलाएर राख्ने । त्यसपछि पानी खन्याई फिल्टर प्रयोग गर्न सकिन्छ ।

6. Now the filter can be used again

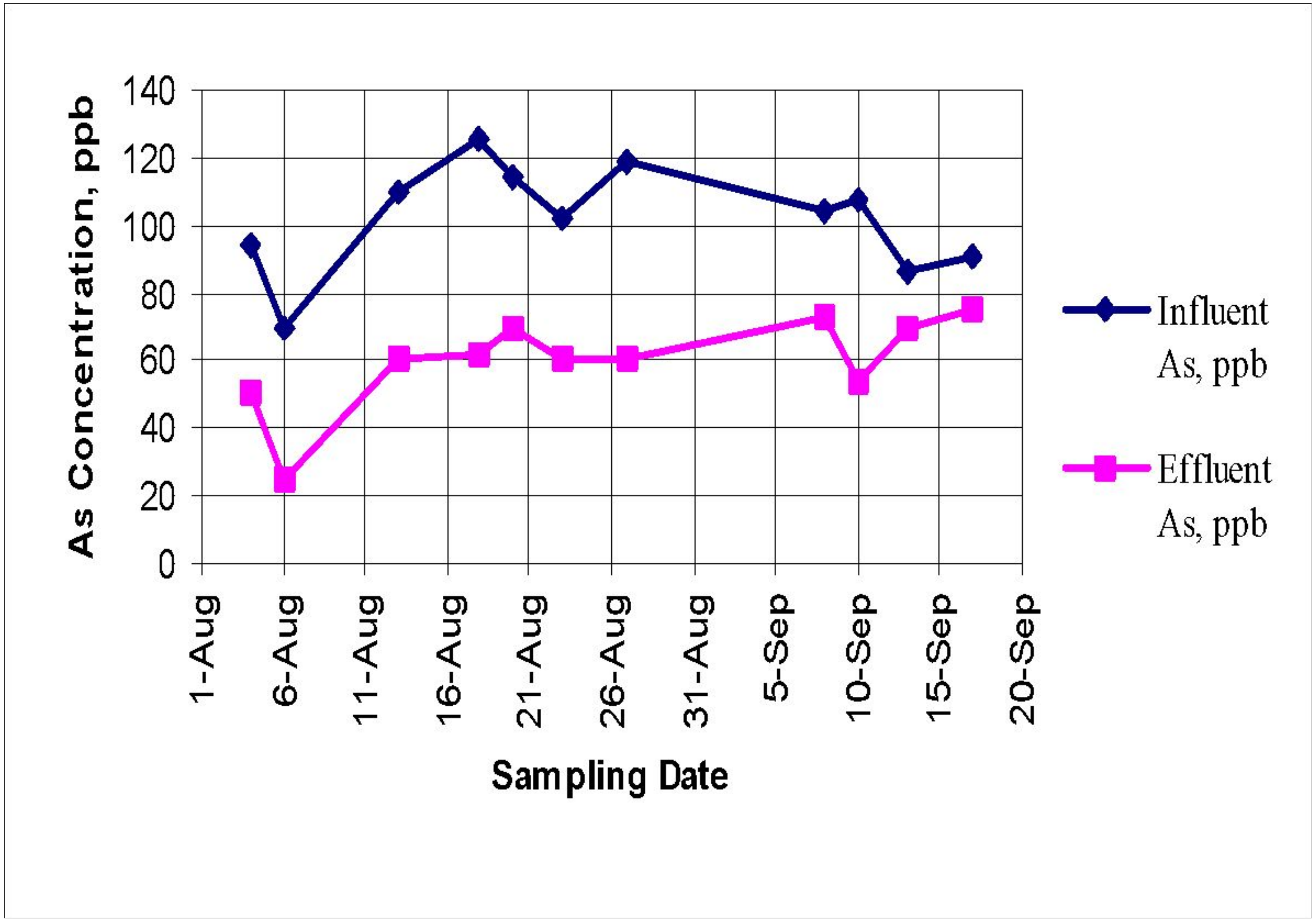

Odell Study - Filter A (5.0kg iron nails)
Arsenic concentration (ppb)
350
300
250
200
150
100
50
0
Filtered Water
Raw Water
8-Oct-03
28-Oct-03
17-Nov-03
7-Dec-03
27-Dec-03
16-Jan-04
5-Feb-04
25-Feb-04
16-Mar-04
5-Apr-04
Date



Odell Study - Filter B (2.5kg iron nails)
Arsenic concentration (ppb)
350
300
250
200
150
100
50
0
Filtered Water
Raw Water
8-Oct-03
28-Oct-03
17-Nov-03
7-Dec-03
27-Dec-03
16-Jan-04
5-Feb-04
25-Feb-04
16-Mar-04
5-Apr-04
Date


Pandey Study – 4 cycles of continual arsenic monitoring
Same Raw Water Sources for All Filters @ 250 ppb
Arsenic concentration (ppb)
Cycle
KAF1
KAF2
KAF3
KAF4
0
10
20
30
40
50
60
70
80
1
2
3
4

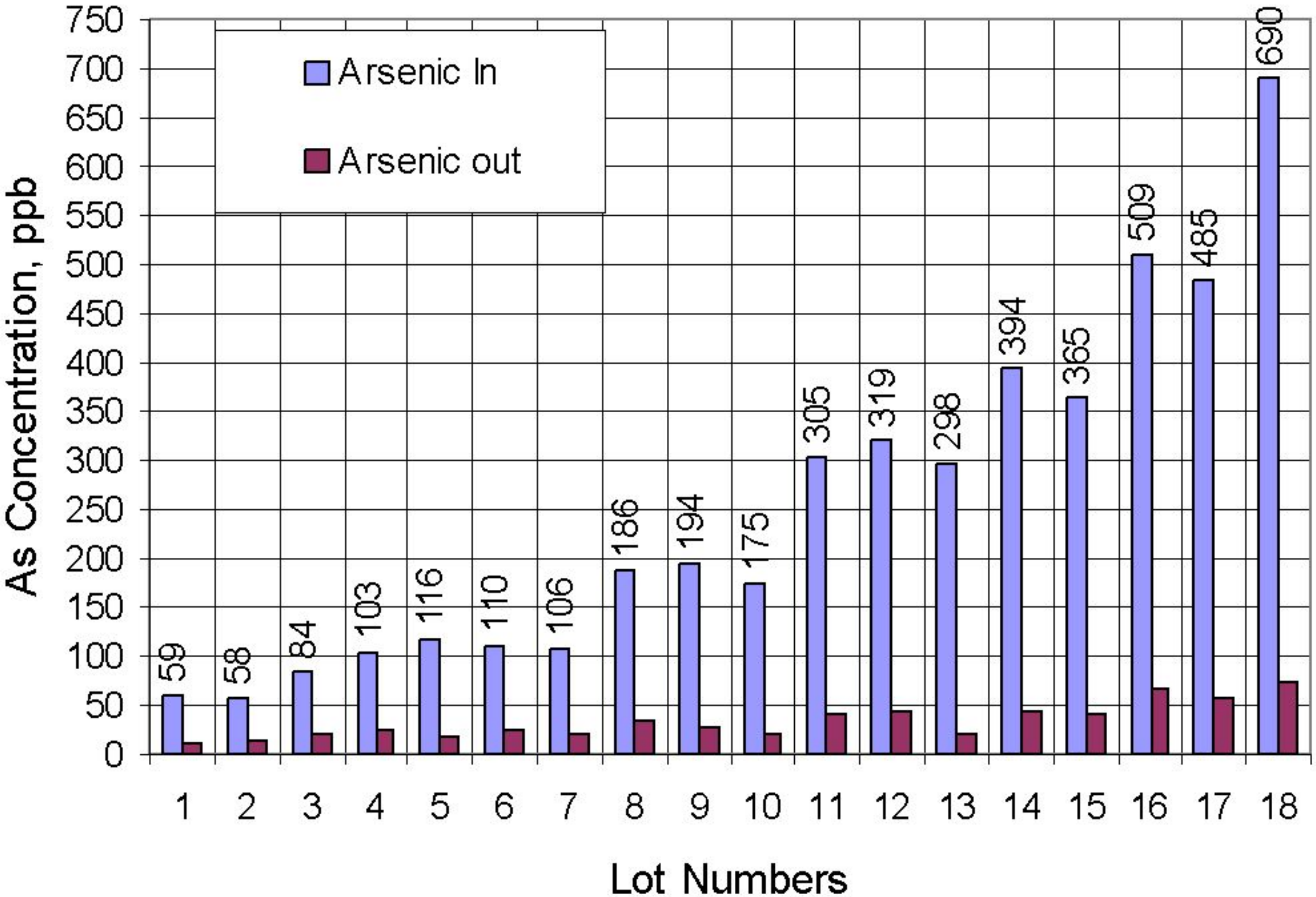
Shrestha Study – Phase 1 Arsenic Results



1200 liters of water filtered

Poor arsenic removal believed to be due to high phosphate in the raw water (31 ppm)

Shrestha Study – Phase 2 Arsenic Results



1800 L of water filtered.

Phosphate in the water is only 0.4 ppm

Arsenic removal efficiency = 85%

Shrestha Study – Phase 2 Total Coliforms Results

Lot No.	Inlet	Outlet	Removal	% Removal
1	500	20	480	96
2	500	40	460	92
3	200	10	190	95
4	500	40	460	92
8	500	20	480	96
9	500	30	470	94
13	500	50	450	90
15	300	20	280	93
17	300	20	280	93
18	300	20	280	93

Filtered 1600 L of tap water artificially spiked with sewage.
Total Coliforms removal efficiency = 94%

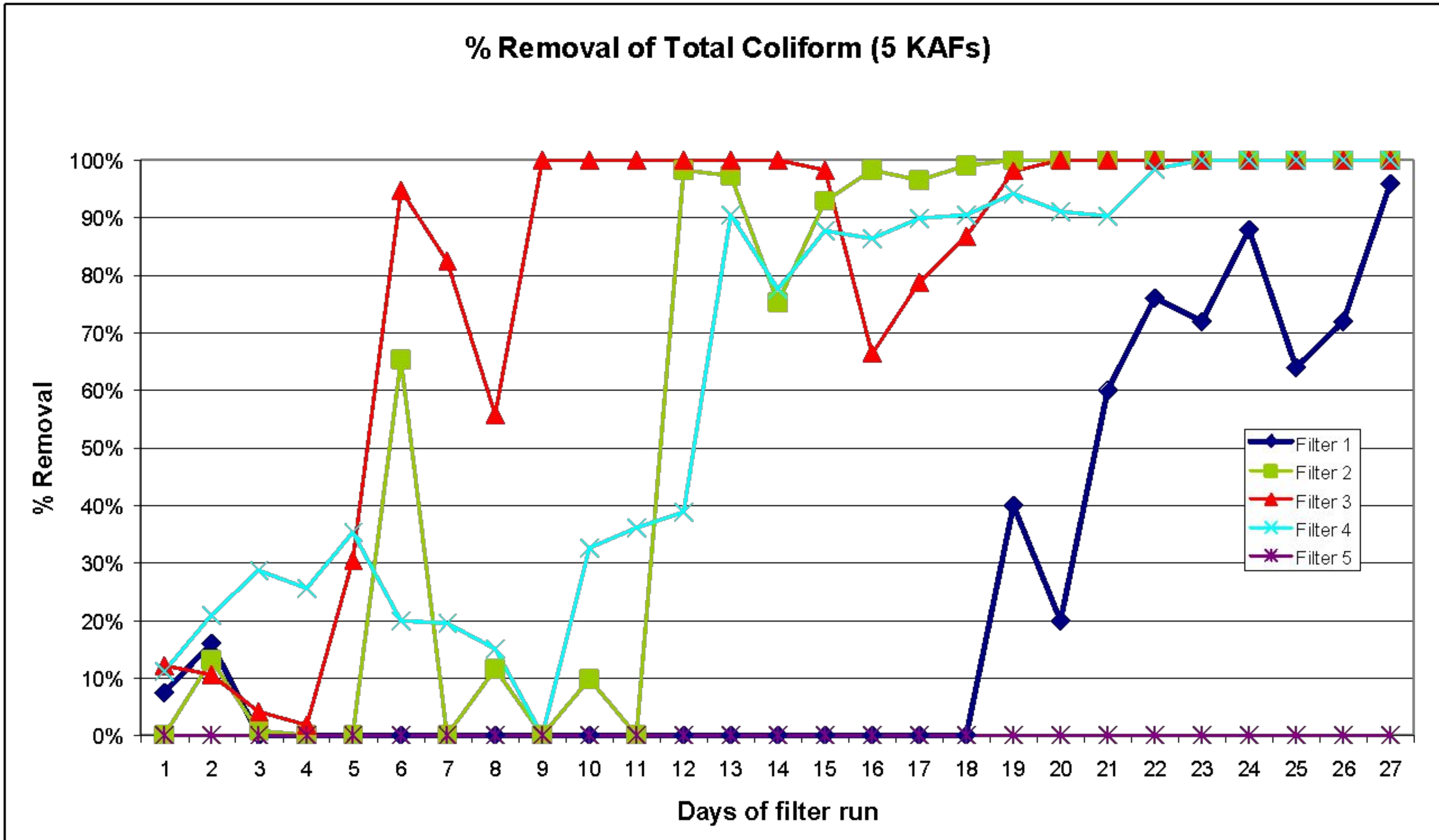
Shrestha Study – Phase 3 Arsenic Results

S.N.	Cumulative Volume	As inflow, ppb	As out flow, ppb	Removal ppb	Percentage removal	Remarks
1	100	73	7	66	90	
2	200	75	7	68	91	
3	300	85	6	79	93	
4	400	70	15	55	79	Tube well 1
5	500	118	1	117	99	
6	600	115	5	110	96	
7	700	110	5	105	95	Tube well 2
8	800	172	15	157	91	
9	900	172	10	162	94	
10	1000	189	33	156	83	Tube well 3
11	1100	203	6	197	97	
12	1200	220	15	205	93	
13	1300	203	46	157	77	
14	1400	198	18	180	91	Tube well 4

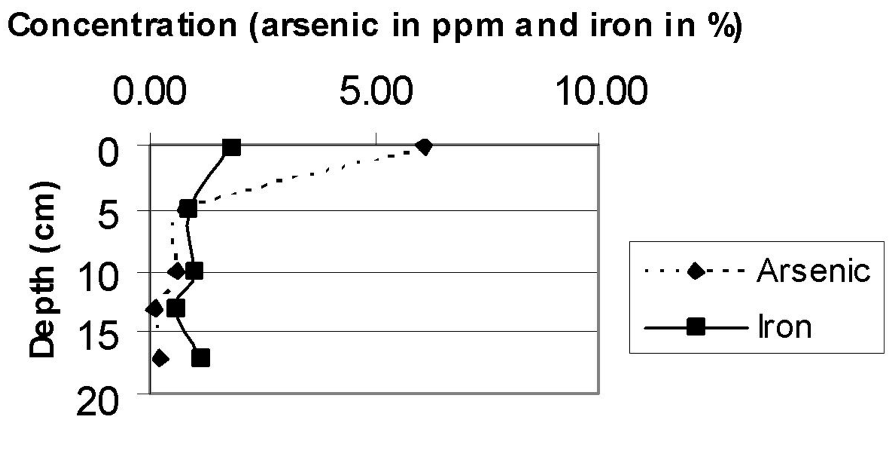
1600 L of water filtered.

Arsenic removal efficiency = 91%

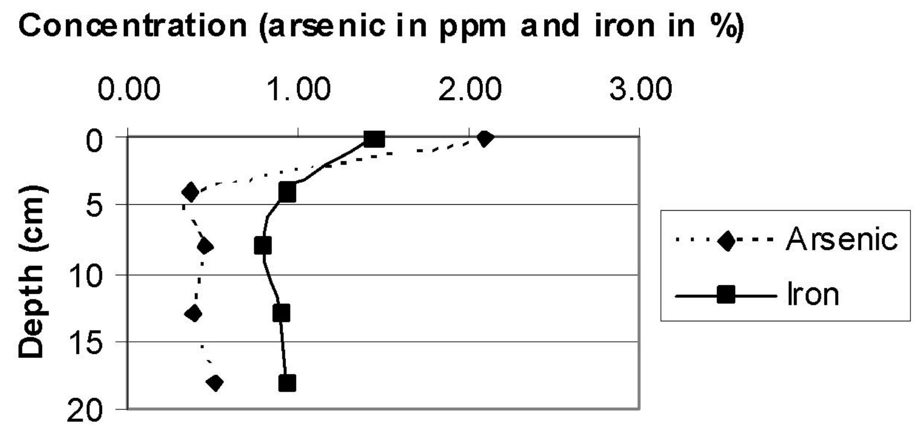
Dipina Sharma Study



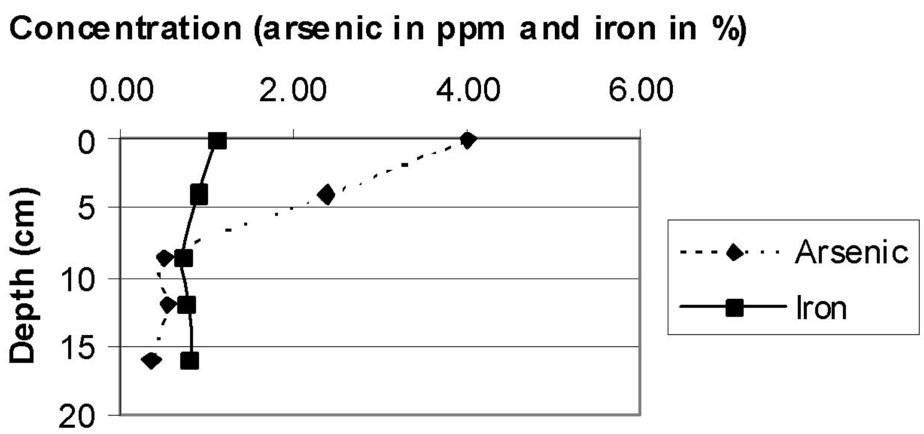
Ghimire Study - Arsenic and Iron Concentration Profiles



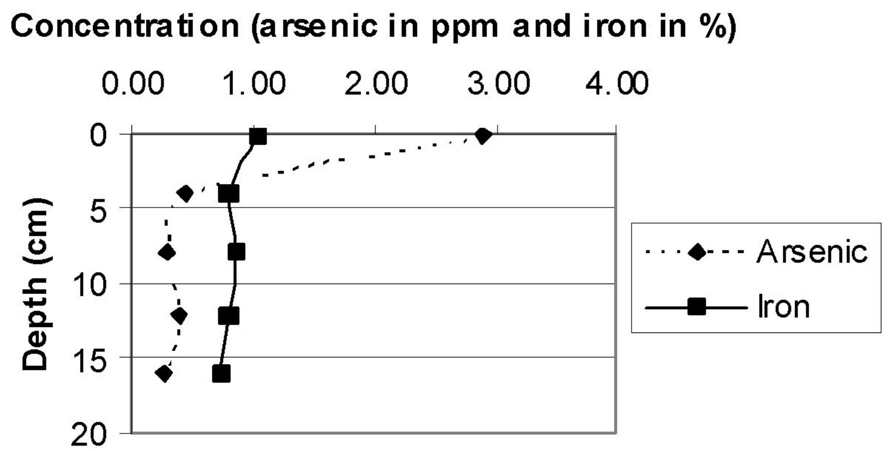
Filter 1 (12-months)



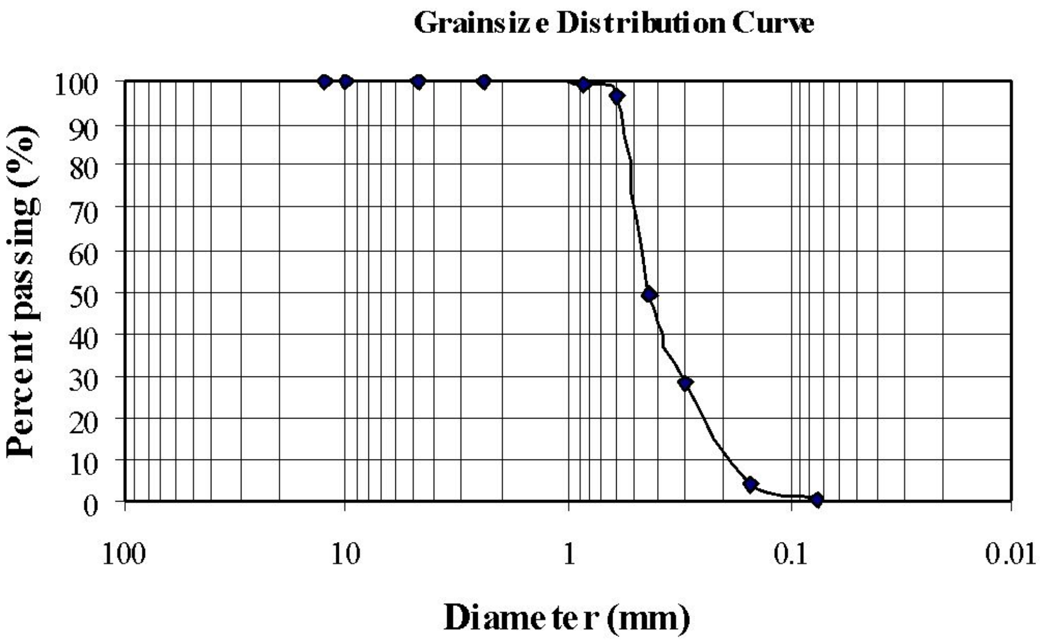
Filter 2 (12-months)



Filter 3 (5-months)

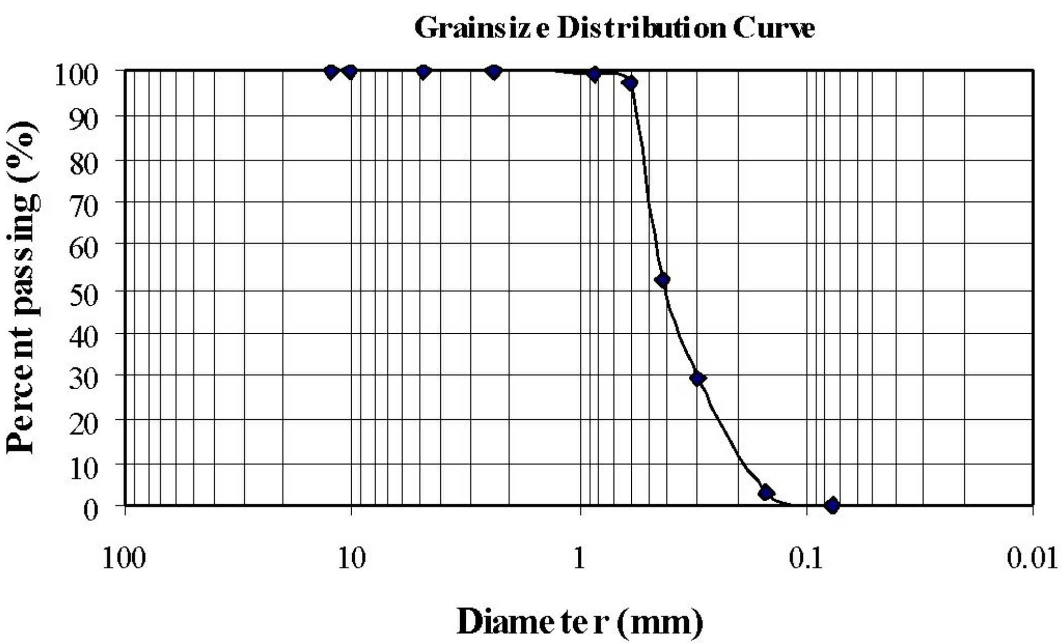


Filter 4 (5-months)



Grainsize Distribution for Filter 1 (12-months old)

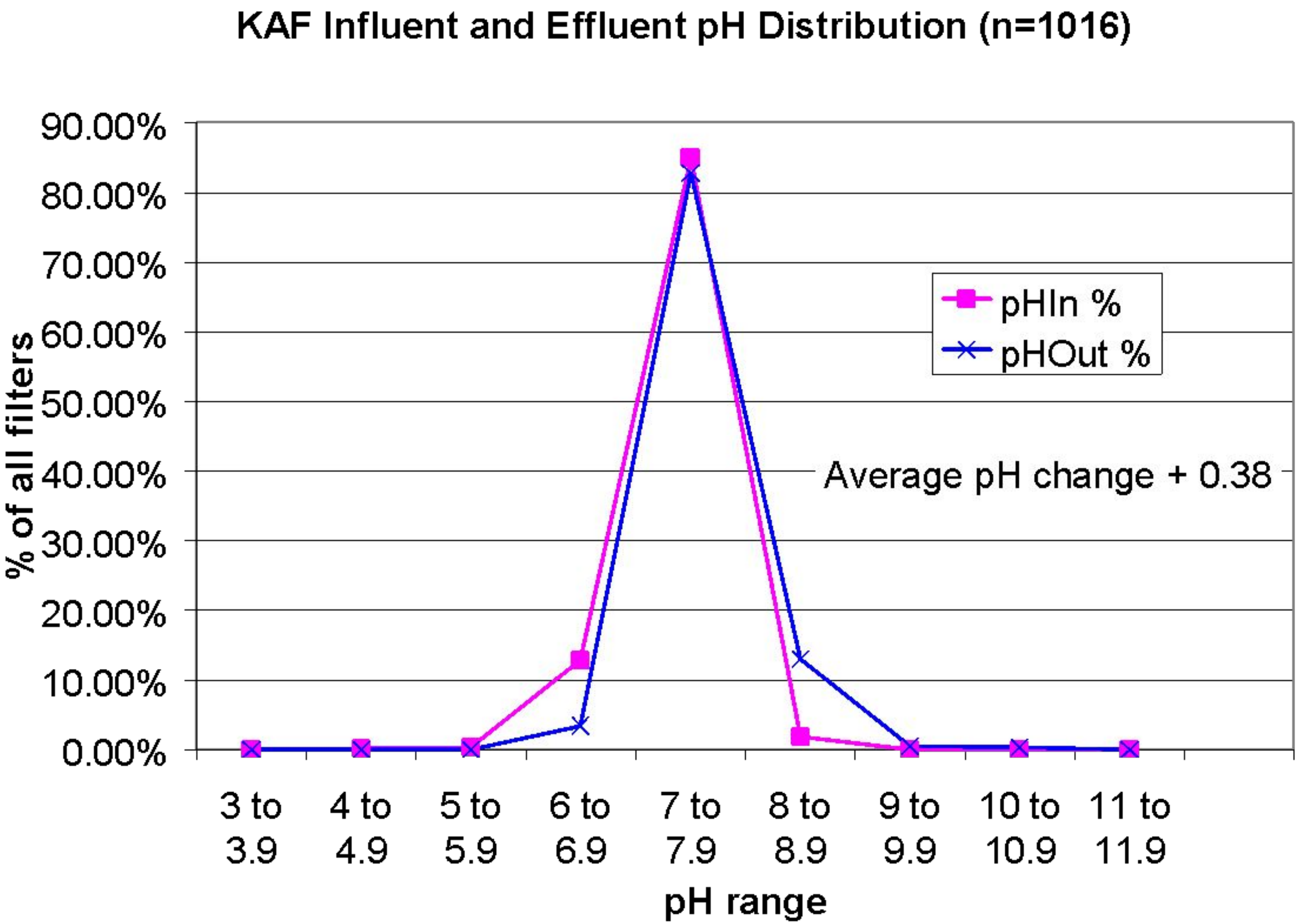
D10 = 0.19
D30 = 0.31
D60 = 0.46
Uniformity coefficient 2.4



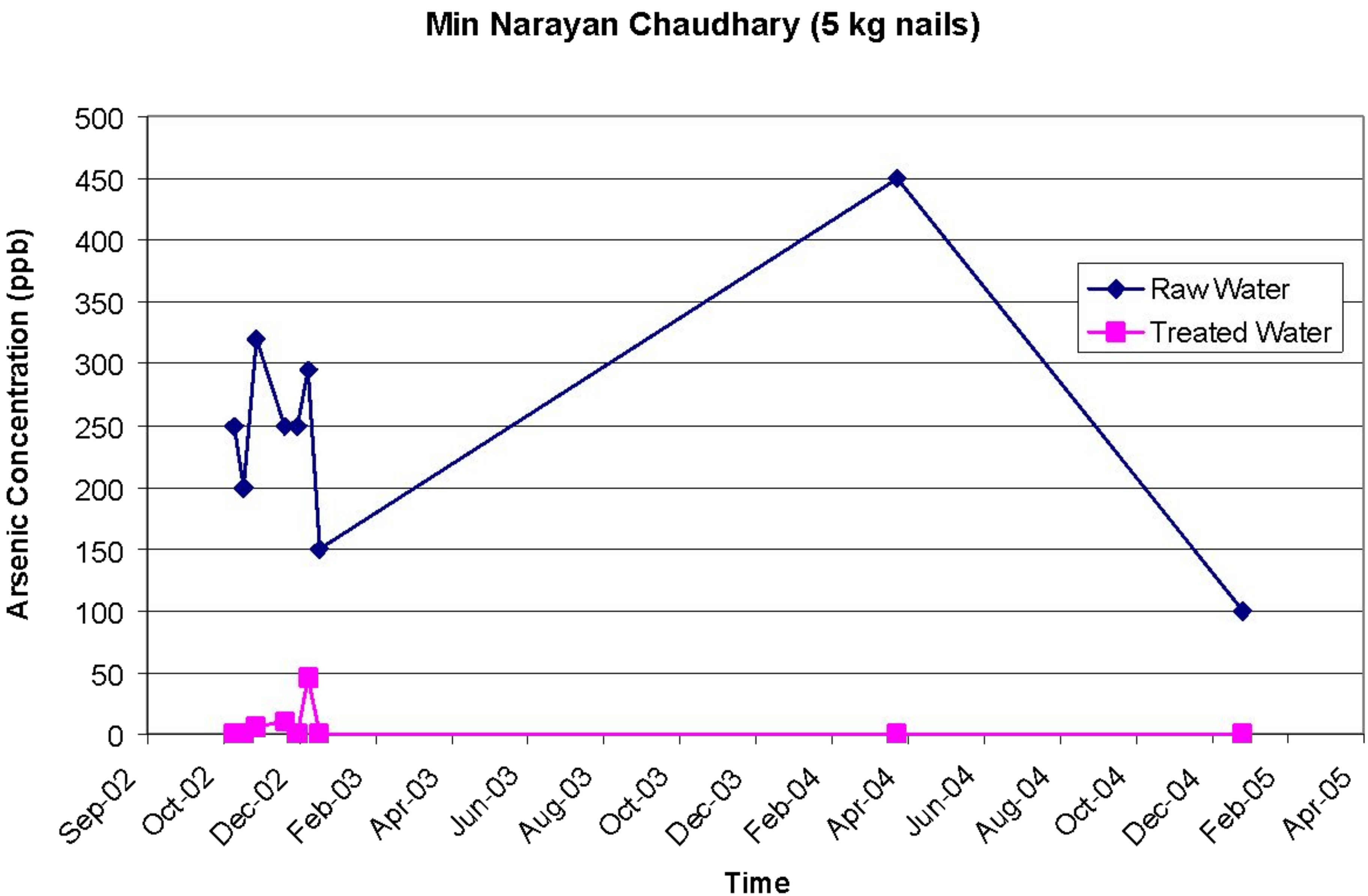
Grainsize Distribution for Filter 3 (5-months old)

D10 = 0.19
D30 = 0.30
D60 = 0.46
Uniformity coefficient 2.4

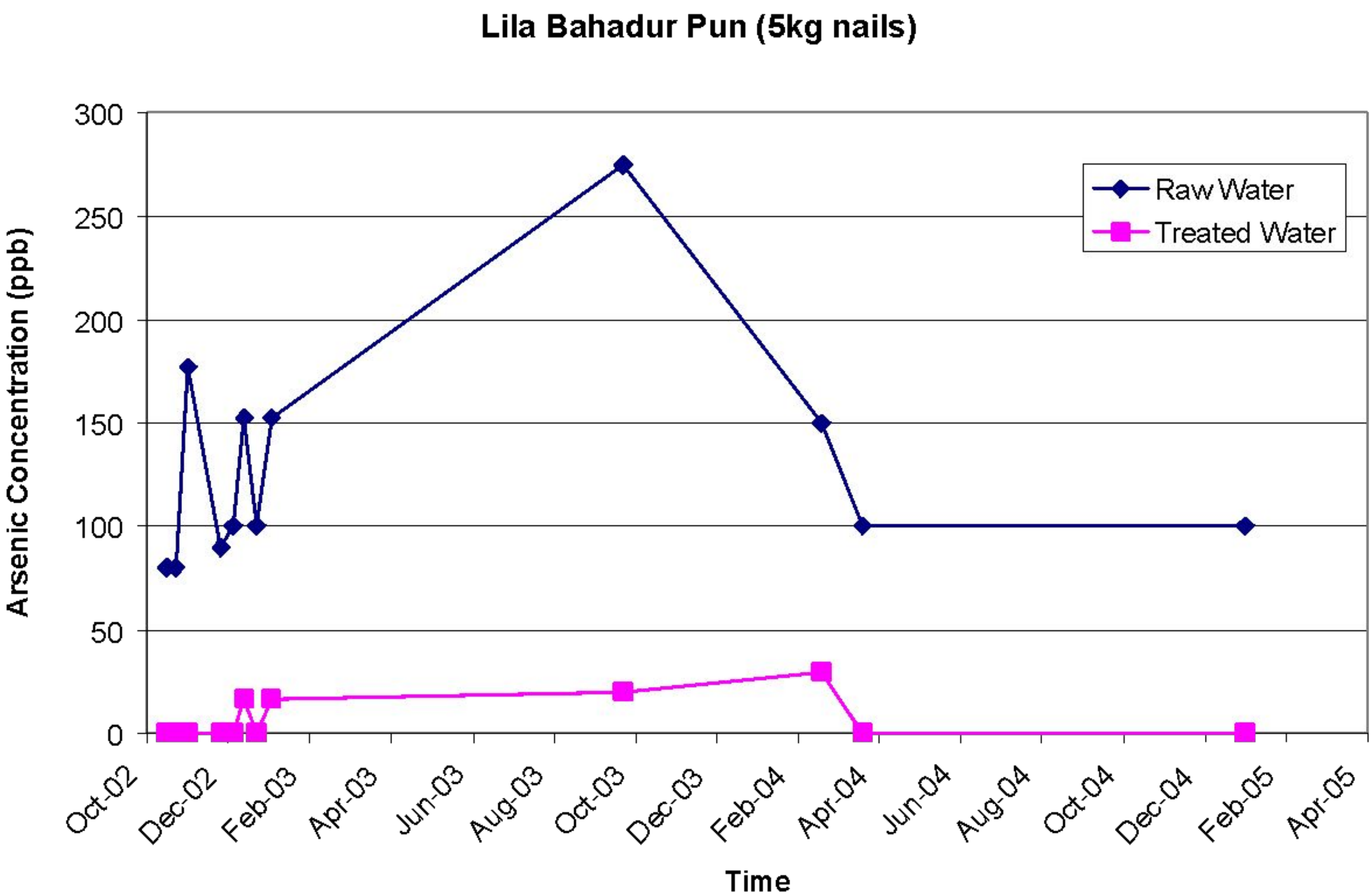
pH Distribution
(all filter version, monitoring Nov04 to Mar05, n=1016)



Arsenic Performance – Long Term



Arsenic Performance – Long Term



Arsenic Performance – Long Term