Evaluation of 8 arsenic removal technologies in Nepal

ABSTRACT

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Over the past two years, a coalition of NGOs and water agencies in Nepal has focused attention chiefly on the occurrence of arsenic and its public health effects. A team of Masters of Engineering students at the Massachusetts Institute of Technology has been a partner in this effort, being the first to investigate tubewell treatment options for Nepal. To date, eight different technologies have undergone a Phase I evaluation. Phase I assessment criteria include performance under field conditions in Nepal (i.e. total arsenic removal below the interim Nepal guideline of 50 μg/L), cost, sludge, and several aspects of social acceptability (i.e., simple to construct and operate, use of local materials). The technologies investigated to date include six adsorption systems and two co-precipitation/filtration systems: 1) three-gagri with iron filings, 2) jerry can with iron filings, 3) iron-coated sand, 4) & 5) two different systems using activated alumina metal oxides, 6) ENPHO arsenic treatment system, 7) a community-based arsenic treatment plant, and 8) Arsenic Biosand Filter.

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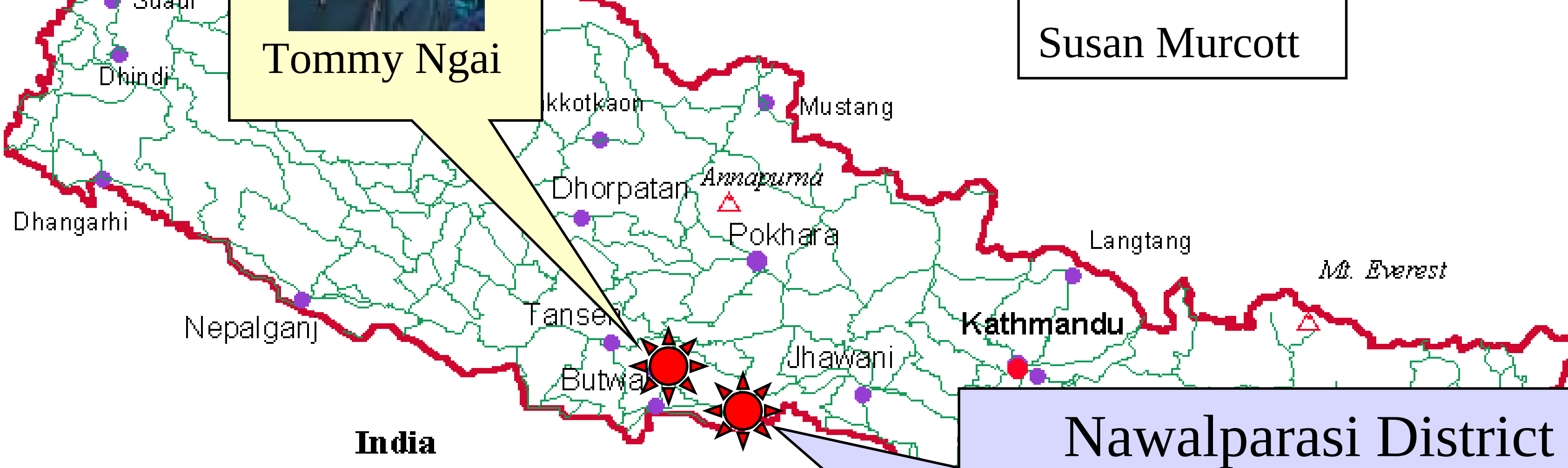
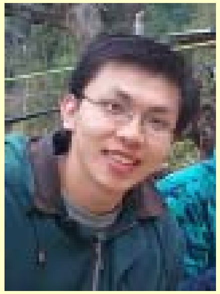
Nepal Project Sites



Rupandehi District

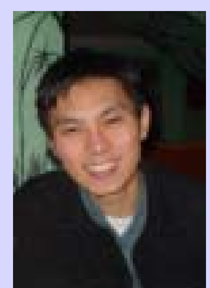


Tommy Ngai

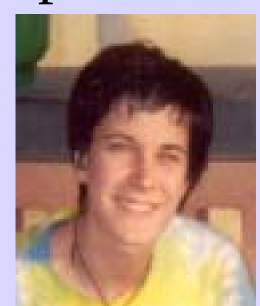
Everywhere

Susan Murcott

Nawalparasi District



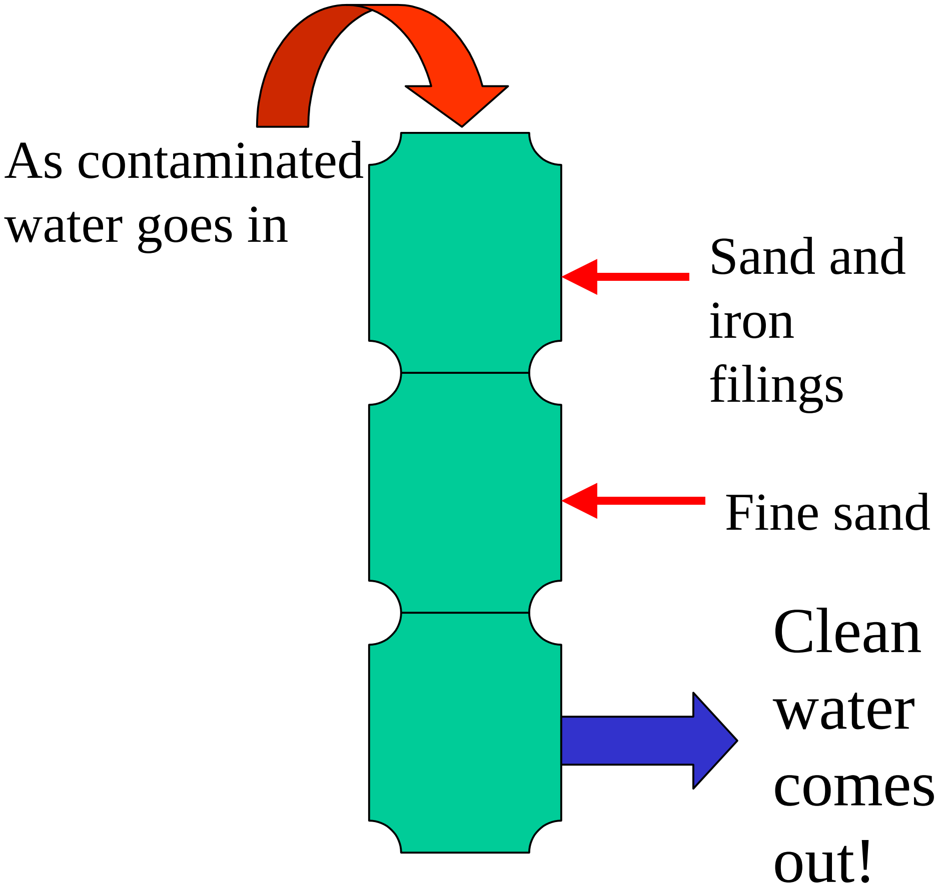
Jeff Hwang



Jessie Hurd

Barika Poole

Three-Gagri System



The real thing!

Construction:

• Top gagri:	iron filings	3 kg
	coarse sand	2 kg
• Middle gagri:	fine sand	2 kg
• Bottom gagri:	used as a collection pitcher	

Treatment Process:

- Adsorption, Precipitation, and Filtration

Cost/Availability:

- ~US$10.50 for gagris and iron
- Gagris readily available in large towns
- Iron filings not easily found, nails may work

Social/Environmental issues:

- Flowrate ~4L/hour, but slower with each run
- Breakthrough ~7000L (500 μg/L to 60 μg/L)
- Constructed from familiar materials
- Simple initial set-up and low maintenance

Field Results:

- 9 runs using influent water with arsenic at ~242 μg/L
- SUCCESS! Effluent concentration <20 μg/L for all 9!

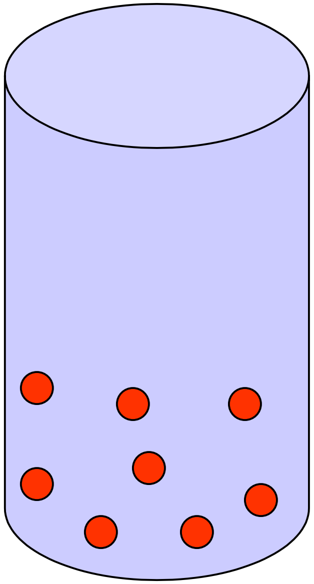
Raw water	Influent Total As (μg/L)	Effluent Total As (μg/L)	% Arsenic Removal
1. Parasi, Nawalparasi	242	11	95%
2. Parasi, Nawalparasi	242	BDL	>98%
3. Parasi, Nawalparasi	242	6	98%
4. Parasi, Nawalparasi	242	BDL	>98%
5. Parasi, Nawalparasi	263	BDL	>98%
6. Parasi, Nawalparasi	212	BDL	>98%
7. Parasi, Nawalparasi	244	BDL	>98%
8. Parasi, Nawalparasi	242	BDL	>98%
9. Parasi, Nawalparasi	252	8	97%

BDL = Below Detection Limit = <5 μg/l

Jerry Can

1. Fill 10 L plastic jug with As contaminated water.

2. Add pre-measured packet of iron filings



3. Allow 3 hours for As to sorb to iron.

4. Decant treated water

Construction:

- Plastic jug 10 L
- Zero-valent iron filings 6.25 g

Treatment Process:

- Adsorption, Precipitation, and Sedimentation

Cost/Availability:

- ~US$0.50 for jug
- Jugs readily available
- Iron filings not easily found

Social/Environmental issues:

- Constructed from familiar materials
- Simple set-up no maintenace
- Literature claims iron can be used 100 times

Field Results:

- 3 runs using influent water with arsenic at ~242 μg/L
- FAILED. No reduction in arsenic concentration in effluent samples.

Raw water	Time in Jug (minutes)	Influent Total As (mg/L)	Effluent Total As (mg/L)	% Arsenic Removal
1. Parasi, Nawalparasi	180	186	186	0%
2. Parasi, Nawalparasi	180	242*	244	0%
3. Parasi, Nawalparasi	45	242*	260	0%

*Influent sample was not analyzed so average concentration is given

Iron Oxide Coated Sand (IOCS)

Construction:

• Prepared Iron Coated Sand	7 L
• Medium Sand	some
• Gravel	some

• Plastic/PVC pipe or similar setup
• Buckets, 10L and 20L

Cost/Availability:

• Chemicals (iron nitrate, NaOH, HCl)	$ 4.2/yr
• Buckets, pipes	$ 3.0/yr

• Chemicals not easily found, PVC pipe available everywhere

Social/Environmental issues:

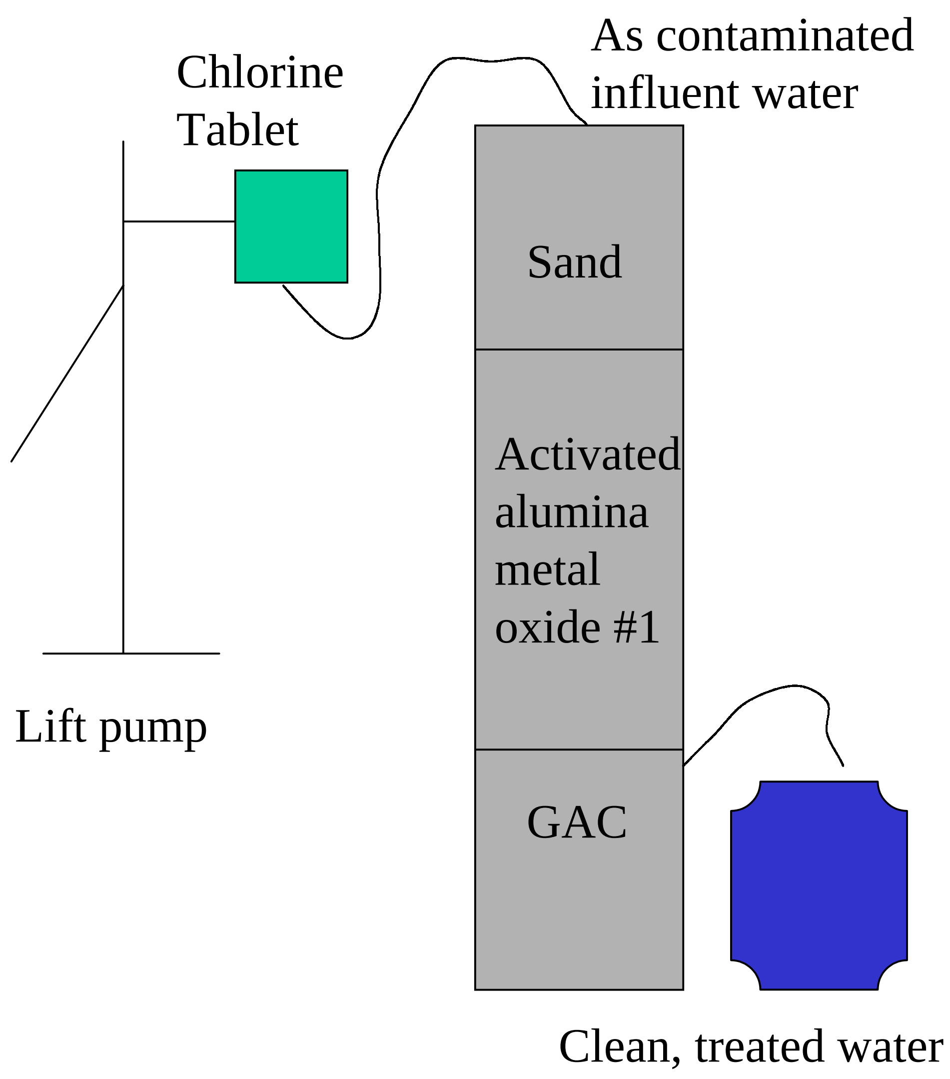
• Sand preparation quite troublesome
    - high oven temperature (up to 550°C)
    - dangerous chemicals (concentrated NaOH, HCl)
    - long preparation time (2 days)
• Easy operation and maintenance
• High flowrate (>20L/hr)
• Arsenic tightly bound to A/M surface, low risk of leaching

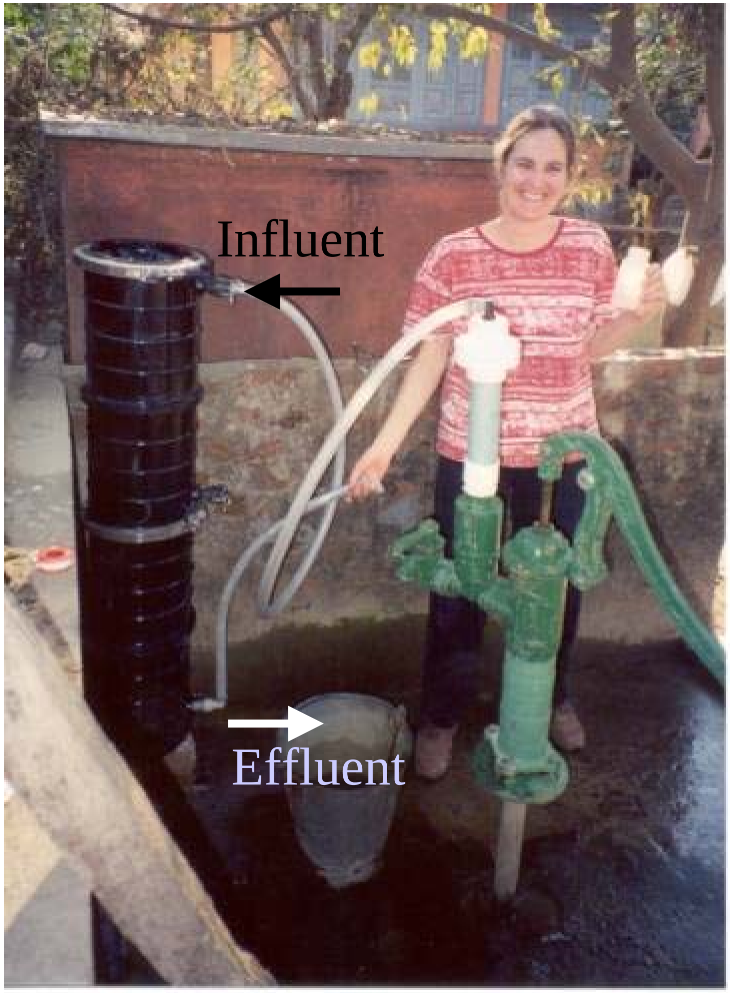
7 different IOCS were prepared, results for the “best sand” are shown

Raw water	Influent Total As (μg/L)	Effluent Total As (μg/L)	% Arsenic Removal
1. Pepperell, MA	101	BDL	>90%
2. Pepperell, MA	101	BDL	>90%
3. Pepperell, MA	101	BDL	>90%
4. Salem, NH	1020	13	99%
5. Salem, NH	1020	126	88%
6. Salem, NH	1020	186	82%
7. Salem, NH	1020	162	84%
8. Salem, NH	1020	194	81%

BDL = Below Detection Limit = <10 μg/L

Activated Alumina Metal Oxide #1
(Apyron Aqua-Bind Media)





Construction:

• Chlorine Tablet	3 tablets
• Sand	~ 25 L
• Activated Alumina Metal Oxide #1	~ 25 L
• Granular Activated Carbon	~ 25 L

Treatment Process:

• Adsorption and Filtration

Cost/Availability:

• ~US$2,000 – includes 5-yr warranty
• Media change: ~US$300 per year
• Only available through Atlanta based Apyron Technologies

Social/Environmental issues:

• Can be used for entire community
• Flowrate ~810 L/hour
• Some maintenance: needs backwashing
• Spent media passed TCLP test, low risk of leaching

Field Results:

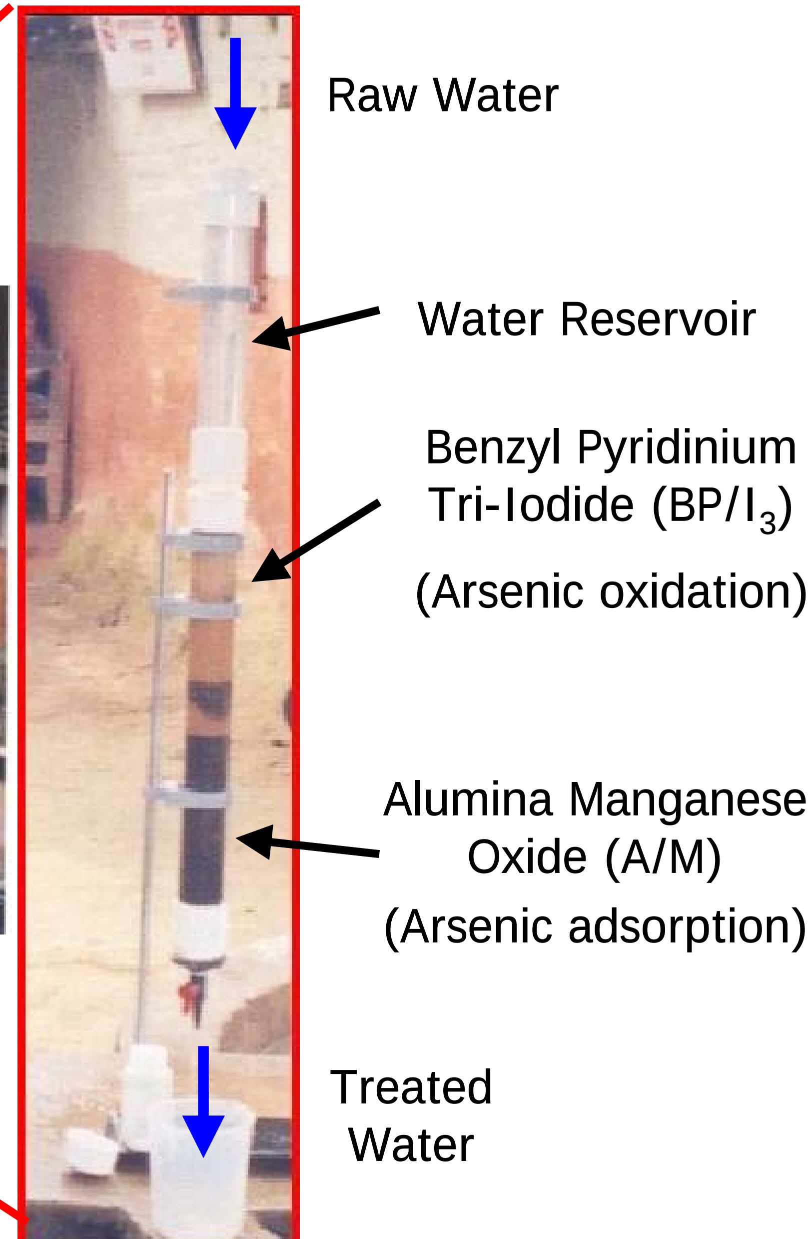
• 10 runs using influent water with arsenic at ~242 μg/L
• SUCCESS!. Effluent concentration <5 μg/L for all 10!

Raw water	Influent Total As (μg/L)	Effluent Total As (μg/L)	% Arsenic Removal
1. Parasi, Nawalparasi	141	BDL	>96%
2. Parasi, Nawalparasi	314	BDL	>98%
3. Parasi, Nawalparasi	369	BDL	>98%
4. Parasi, Nawalparasi	315	BDL	>98%
5. Parasi, Nawalparasi	349	BDL	>98%
6. Parasi, Nawalparasi	245	BDL	>98%
7. Parasi, Nawalparasi	232	BDL	>98%
8. Parasi, Nawalparasi	251	BDL	>98%
9. Parasi, Nawalparasi	250	BDL	>98%
10. Parasi, Nawalparasi	375	BDL	>99%

BDL = Below Detection Limit = <5 μg/L

Activated Alumina Metal Oxide #2

(Aquatic Treatment Systems, Inc.)



Construction:

- Benzyl Pyridinium Tri-Iodide (BP/I_3) media 0.4 L
- Activated Alumina Manganese Oxide (A/M) media 0.8 L
- A plastic/PVC pipe or similar setup

Treatment Processes:

Oxidation, Surface Adsorption/Complexation

Cost/Availability:

- BP/I_3 media \$15/year
- A/M media \$ 3/year
- PVC pipe or similar setup \$ 2

Both media not available in Asia currently, PVC pipe easily found

Social/Environmental issues:

- Easy to construct, operate and maintain
- High flowrate (>20L/hr)
- Reduces iron, color, turbidity
- Arsenic permanently bound to A/M surface, low risk of leaching

Field Results:

- BP/I_3 seems not necessary. A/M itself observed to reduce total As to < 5 μg/L

Raw water	Influent Total As (μg/L)	Influent % As (III)	Effluent Total As (μg/L)	% arsenic removal
1. Parasi, Nawalparasi	242	91%	BDL	>98%
2. Parasi, Nawalparasi	152	89%	BDL	>97%
3. Parasi, Nawalparasi	337	91%	BDL	>99%
4. Parasi, Nawalparasi	323	73%	BDL	>98%
5. Madangram, Rupandehi	863	94%	BDL	>99%
6. Madangram, Rupandehi	328	98%	BDL	>98%
7. Madangram, Rupandehi	149	77%	BDL	>97%
8. Sunwal, Nawalparasi	328	81%	BDL	>98%
9. Sunwal, Nawalparasi	147	100%	BDL	>97%

BDL = Below Detection Limit = <5 μg/L

ENPHO Arsenic Removal System

Chemical packet contains:
- Ferric chloride (coagulant)
- Sodium hypochlorite (oxidant)
- Charcoal (adsorbent)

Raw Water

Mixing & Settling

Filtration (ceramic filter)

Treated Water

Treatment Processes:

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 and Filtration

Cost/Availability:

- Buckets/Filter $4.30/yr
- Chemicals $9.70/yr
- Buckets and filter readily available, chemical is distributed by ENPHO in Nepal only

Social/Environmental issues:

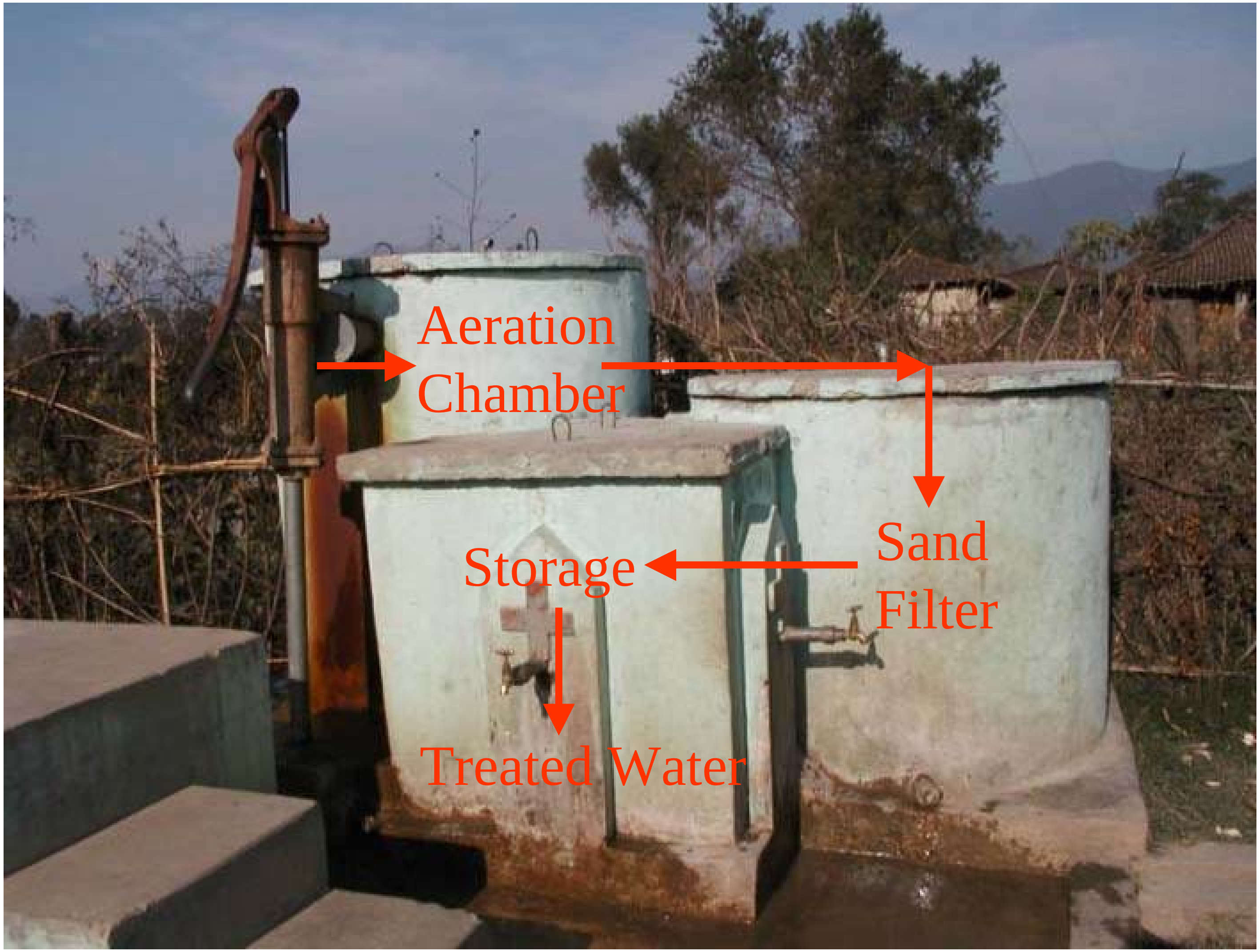
- Flowrate 3-5L/hr
- Arsenic sludge disposal concern
- Good fecal coliform removal, up to 99%

Field Results:

- Effluent total arsenic usually below 50 μg/L but seldomly below 10 μg/L (WHO and USPEA Standard)

Raw water	Influent Total As (μg/L)	Effluent Total As (μg/L)	% Arsenic Removal
1. Parasi, Nawalparasi	90	17	81%
2. Parasi, Nawalparasi	101	12	88%
3. Parasi, Nawalparasi	202	18	91%
4. Parasi, Nawalparasi	202	12	94%
5. Parasi, Nawalparasi	215	9	96%
6. Parasi, Nawalparasi	272	22	92%
7. Parasi, Nawalparasi	274	25	91%
8. Parasi, Nawalparasi	274	16	94%

Arsenic Treatment Plants (ATPs)



Construction:

• Concrete	3 chambers
• Gravel	~ 250 L
• Sand	~ 250 L
• Iron chips/ iron coated gravel	as needed

Cost/Availability:

- Entire plant costs ~$210 and serves one village
- Designed and built by ENPHO using locally available material

Social/Environmental issues:

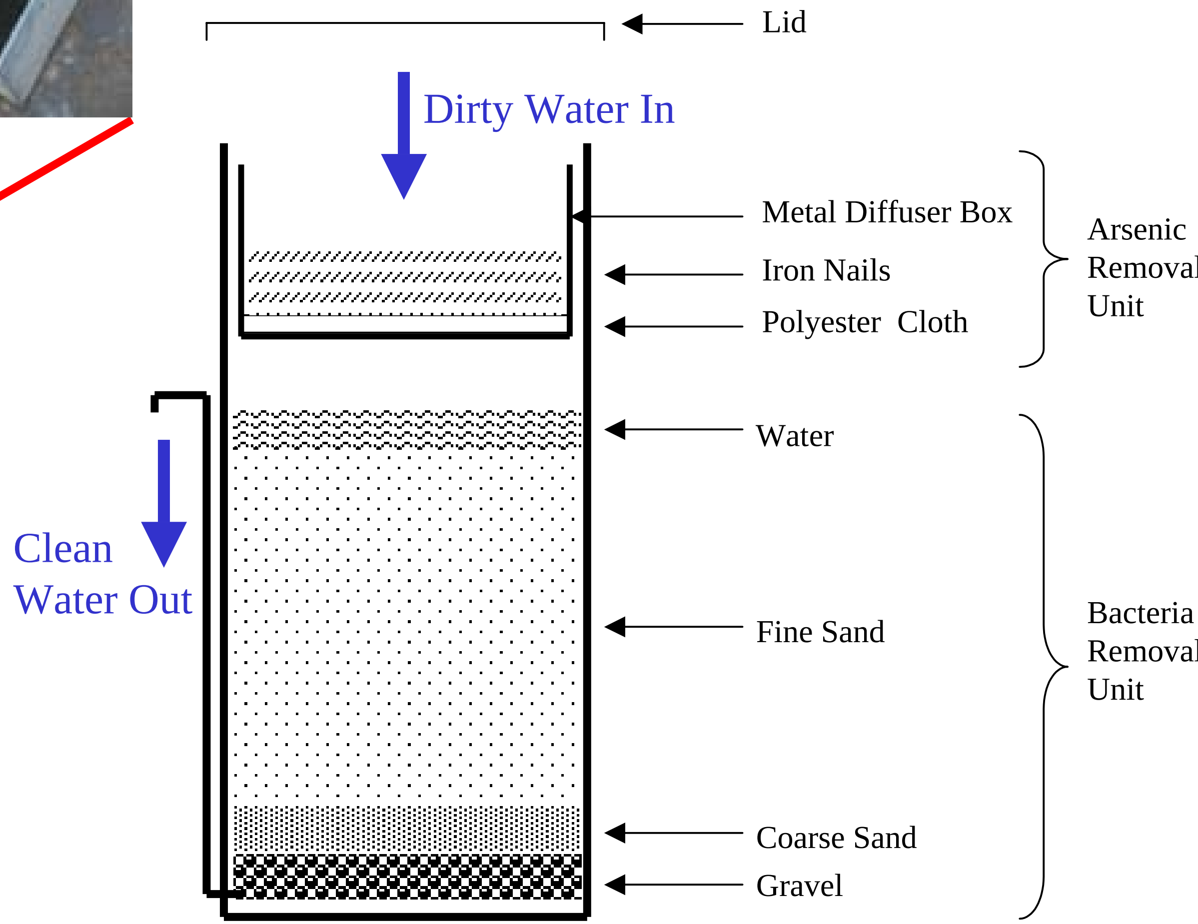
- Centralized location, not so convenient for some households
- Easy operation and maintenance
- High flowrate (>20L/hr)
- Arsenic-Iron sludge disposal problem

Technical issues:

- some ATPs do not work at all due to low iron in raw water

Aresenic Treatment Plants Location	Influent Total As (µg/L)	Influent Solube Fe (mg/L)	Effluent Total As (µg/L)	% Arsenic Removal
1. Rupauliya, Nawalparasi	102	6.5	16	84%
2. Baluna, Nawalparasi	73	2.0	41	44%
3. Ranipakad, Nawalparasi	75	1.5	66	12%
4. Badera, Nawalparasi	130	6.0	16	88%
5. Laxmipur, Nawalparasi	37	1.5	35	5%

Arsenic Biosand Filter (ABF)



Construction:

• concrete	0.1 m^3
• fine sand, coarse sand, gravel	0.5 m^3
• iron nails	5 kg
• diffuser box (metal or plastic)	1
• PVC piping	some

Cost/Availability:

- ~US$20 capital cost
- ~US$ 5/year/household to replace iron
- all materials readily available in rural market

Social/Environmental issues:

- High flowrate 14L/hr
- Easy operation and minimal maintenance
- High level of acceptance among users

Field Results:

- Average arsenic removal = 93%
- Average total coliform and E.Coli removal = 58%, 64%

Raw water	Influent Total As (μg/L)	Effluent Total As (μg/L)	% Arsenic Removal
1. Tilakpur, Nawalparasi	160	15	91%
2. Tilakpur, Nawalparasi	120	BDL	96%
3. Panchanagar, Nawalparasi	60	8	87%
4. Panchanagar, Nawalparasi	120	BDL	96%

BDL = Below Detection Limit = <5 μg/L

CONCLUSIONS

Of the eight technologies assessed, the three top-ranked technologies are:

- three-gagri
- ENPHO arsenic removal system
- Arsenic Biosand Filter

Phase II assessment under pilot project field conditions will involve additional performance criteria (As(III) vs. As(V) removal, microbial contamination), social acceptability to women, the primary users of these arsenic remediation systems, and the economic sustainability of the project.

ACKNOWLEDGEMENTS

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- Roshan Shrestha, Environmental and Public Health Organization (ENPHO)
- Nepal Red Cross Society (NRCS)
- Japanese Red Cross (JRCS)
- Rural Water Supply and Sanitation Support Program (RWSSSP), in partnership with the Finnish International Development Agency (FINNIDA)