Water Quality and Point of Use Treatment Study in Nepal

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Geography

Background - Nepal

- Seventh poorest nation in the world (USAID)
- Dense and growing population in hill and Terai regions
- 70% of population do not have access to clean, safe drinking water (World Resources Institute)

Purpose

- Water Quality:
  - Pinpoint some water quality problems and add to the body of water quality data
- Point-of-Use:
  - Explore and design means of improving drinking water quality on household level

Presentation Outline

- Water Quality Studies
  - Turbidity and Microbial
  - Arsenic
  - Nitrate and Ammonia
- Point of Use Treatment Studies
  - Coagulation and Settling
  - Filtration
  - Disinfection
  - Economics and Logistics

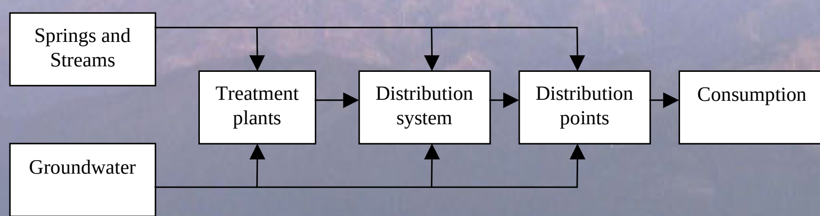
Microbial Contamination of Drinking Water

Andrea Wolfe

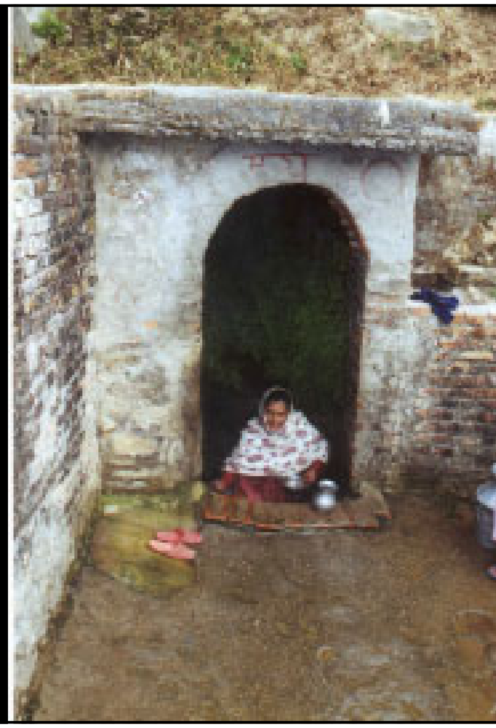
Test Methods

- Turbidity:
  - 2100P Portable HACH Turbidimeter
- Indicator Bacteria:
  - HACH P/A test with MUG reagent
  - HACH MPN H_2S

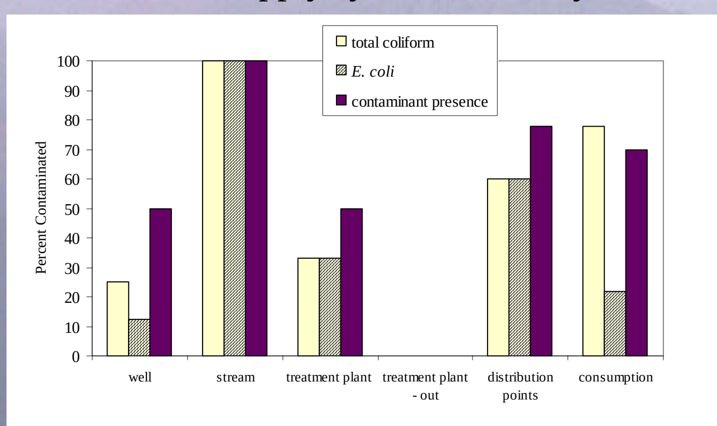
Drinking Water Distribution System



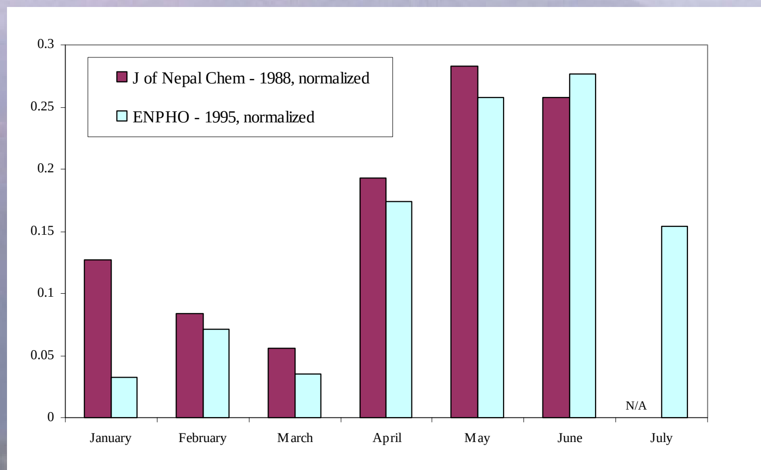
Kathmandu Valley



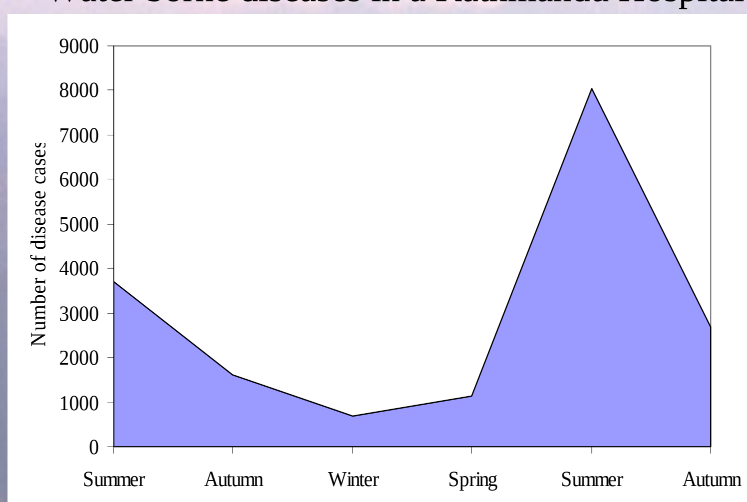
Microbial contamination in the Kathmandu Valley water supply system – January 2000



Normalized seasonal variation of total coliform in the Kathmandu Valley water distribution system.



Water borne diseases in a Kathmandu Hospital



* ENPHO 1995

Summary of Results

- Drinking water that is disinfected in the treatment plant becomes reinfected in the distribution system
- There is a lot of seasonal variation in distributed drinking water quality
- Seasonal variation in drinking water quality corresponds to fluctuations in waterborne disease

Conclusion and Recommendations

- Conclusion:
  – Much of Kathmandu Valley's drinking water is severely contaminated
- Recommendations:
  – Set drinking water standards
  – Define the roles and responsibilities of the water supply agencies
  – Perform regular water quality monitoring

Arsenic Contamination Study

Tricia Halsey

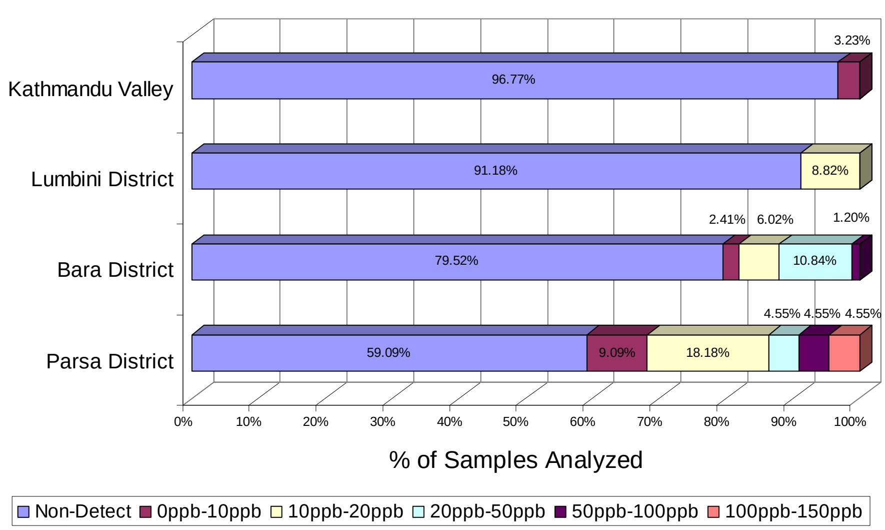
Why do we care about arsenic in Nepal?

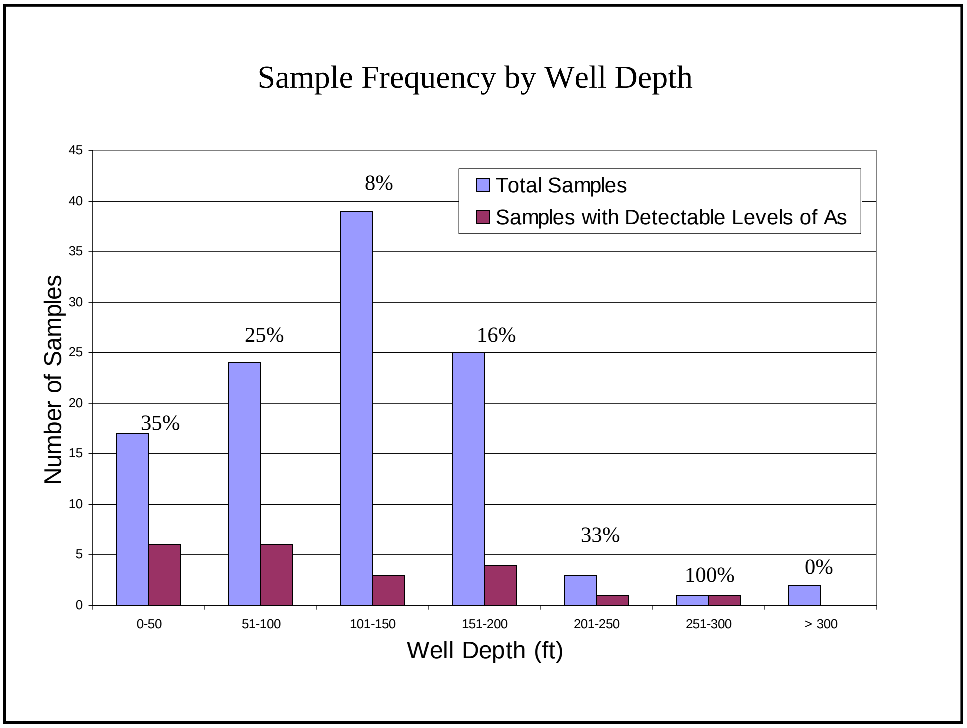
- Toxic chemical
- WHO MCL for As = 10ppb
- Crisis in Bangladesh & India
  - Installation of tube wells several years ago
  - Unknown source generally believed to be nature
  - Found in layer of alluvial deposits
  - Possibility that arsenic will be found in Nepali drinking water

Analytical Methods

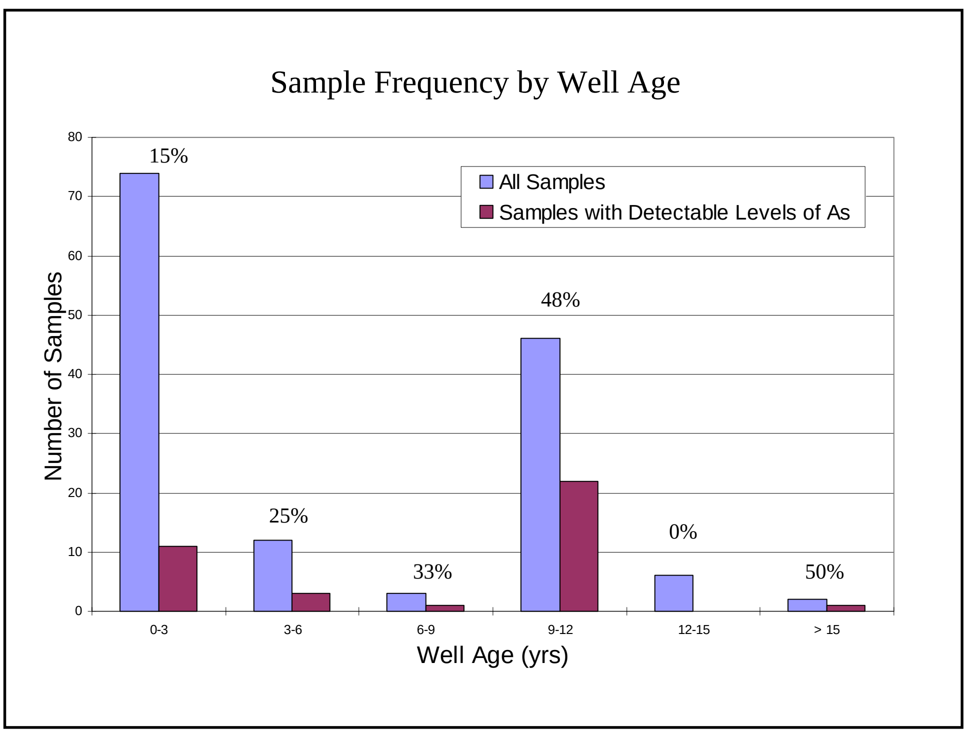
- EM Quant Test Strips
- Affiniti Concentration Kits
- Graphite Furnace Atomic Absorption Spectroscopy (GFAAS)
  - A portion of each sample preserved to 1% acidification with concentrated nitric acid
  - Transported back to MIT for analysis in Ralph M. Parsons Laboratory

GFAAS Results





Sample Frequency by Well Depth
Total Samples
Samples with Detectable Levels of As
Number of Samples
Well Depth (ft)
0-50
51-100
101-150
151-200
201-250
251-300
> 300
35%
25%
8%
16%
33%
100%
0%



Sample Frequency by Well Age
All Samples
Samples with Detectable Levels of As
Number of Samples
Well Age (yrs)
0-3
3-6
6-9
9-12
12-15
> 15
15%
25%
33%
48%
0%
50%

Summary of Results

- No contamination found above the WHO limit in the Kathmandu Valley
- 18% of samples taken from the Terai had arsenic levels above the WHO limit (based on GFAAS)
- Samples with detectable levels of arsenic found in tube wells up to 300 feet deep
- 48% of samples taken from wells aged 9-12 years had detectable levels of arsenic

Conclusions/Recommendations

- Small amount of arsenic contamination in areas of the Terai region that may be of natural origin
- Field kits provide a general indication of mass contamination, but more accurate methods should be used when detailed results are required
- Future study of the following is recommended:
  - testing of tube wells in other districts of the Terai
  - analysis of the geology of the region
  - possible anthropogenic sources

Drinking Water Quality Assessment: Nitrate and Ammonia

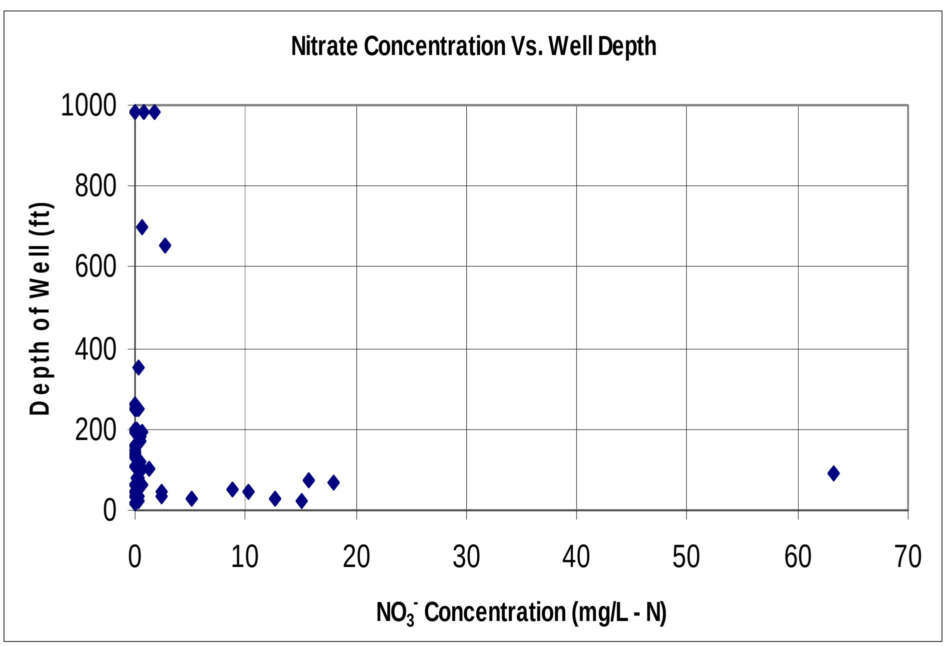
Andy Bittner

Nepal Nitrate and Ammonia Results

- General Results
  - 8.6% contaminated with NO_3^- over WHO guideline of 10 mg/L -N
  - 29% contaminated with NH_3 over the WHO limit of 1.5 mg/L -N
  - Average NO_3^- concentration = 2.37 mg/L -N
  - Average NH_3 concentration = 5.2 mg/L -N

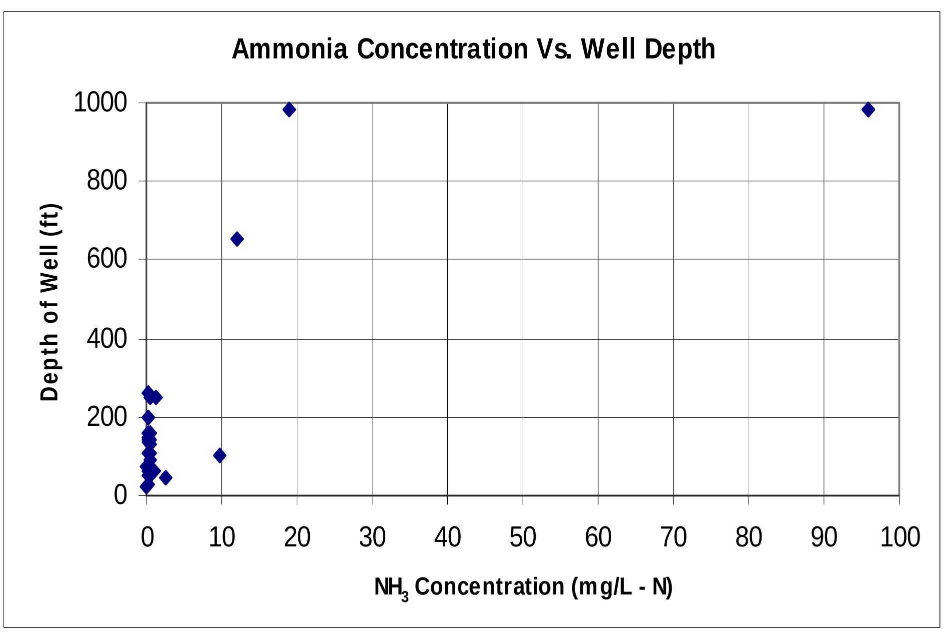
Nitrates vs. Depth

- Nitrates much more prevalent at shallow depths
  - 19% of wells shallower than 50 ft. contaminated with NO_3^- above WHO limit
  - No wells deeper than 100 feet contaminated with NO_3^- above 1 mg/L -N
- Nitrate contamination from surface anthropogenic sources - septic systems and inadequate disposal of sewage wastes



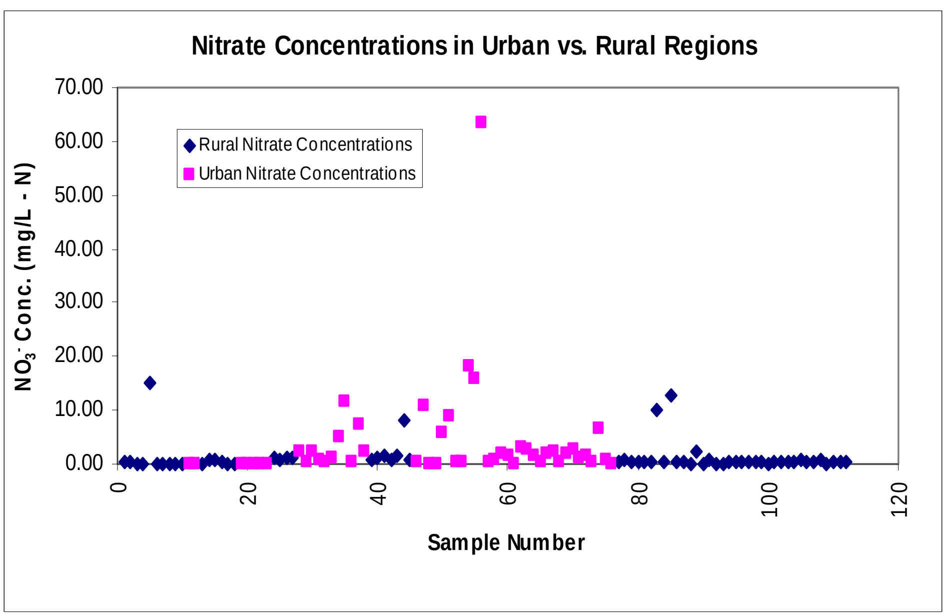
Ammonia vs. Depth

- Ammonia concentrations are relatively low except in deep boring wells - 200-300 m deep
  - Deep boring wells contain average ammonia concentration of 48 mg/L -N
- Ammonia contamination is from geologic causes - presence of deep lignite and peat beds in an anaerobic environment



Nitrate Concentrations in Rural vs. Urban Environments

- Nitrates much more common in urban areas than in rural areas
  - Avg. urban NO_3^- concentration = 3.9 mg/L-N
  - Avg. rural NO_3^- concentration = 1.2 mg/L-N
- Due to prevalence of urban NPS pollutants such as poorly designed septic systems and inadequate containment and treatment of sewage waste
- Possible seasonal fluctuations



Conclusions

- Nitrates common in shallow groundwater sources from anthropogenic NPS contaminants
- Ammonia common in deep groundwater sources from naturally occurring geologic sources
- Urban groundwater sources contain nitrates at much higher concentrations than rural sources

Coagulation and Settling for Applications in Nepal

Kim Luu

Motivation

- Preliminary phase of drinking water treatment

Coagulation → Filtration → Disinfection

Goals

- Find optimum dosage of coagulant
- Applications
  - Water Treatment Plants
  - Point of Use

Experiments Performed

- Coagulants: FeCl3, US Alum, Nepal Alum
- Automated Coagulation
  – Analysis of jartest data
  – Conclusions of optimum dosage

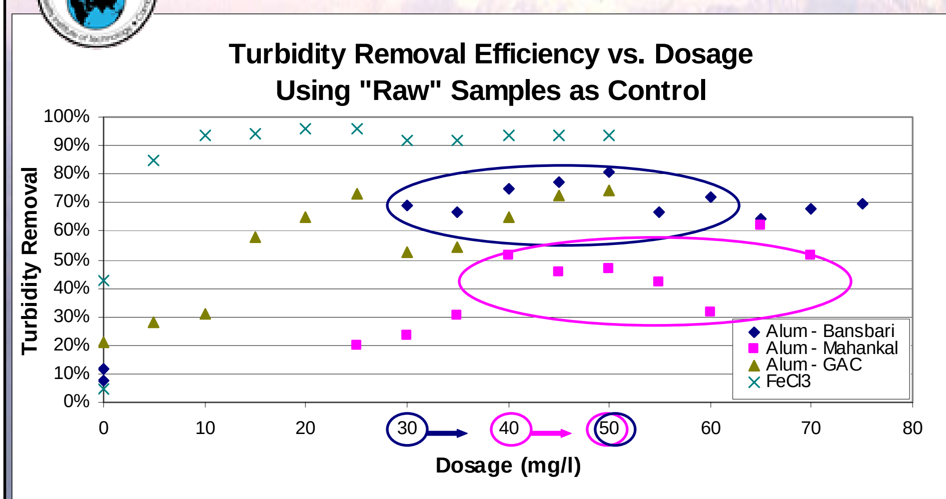
- Manual Coagulation
  – Feasibility

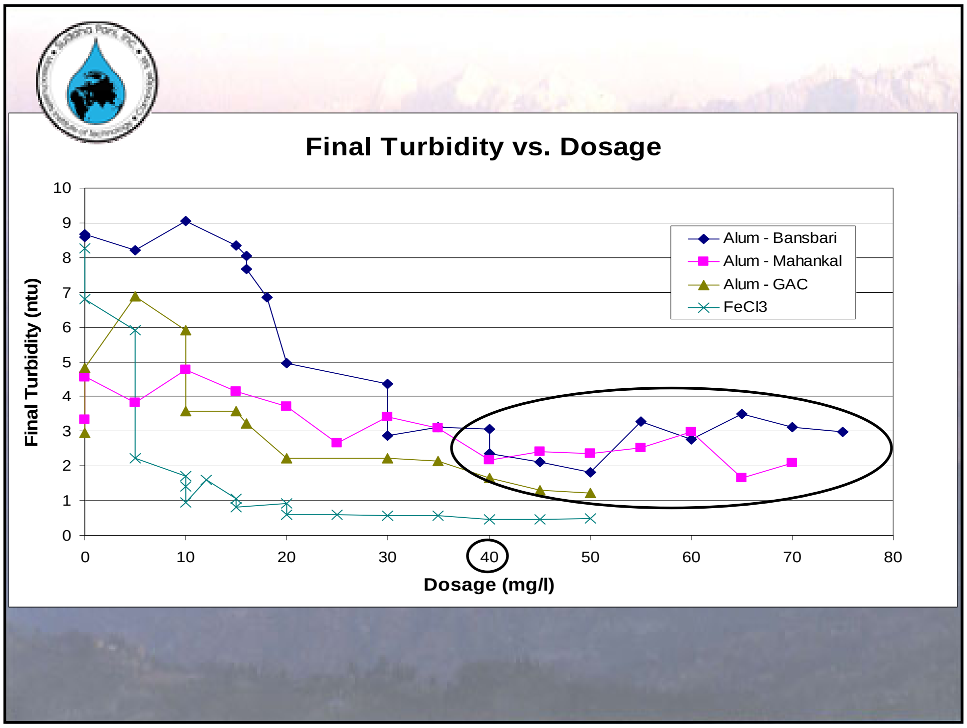
Jartest Experiments

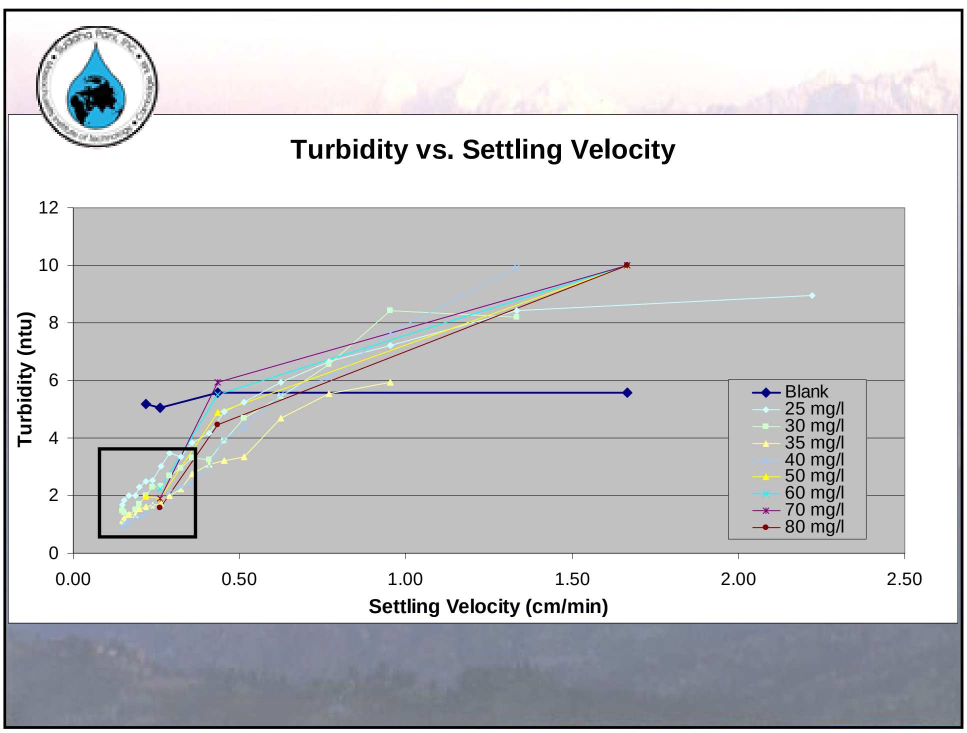
- Rapid Mix
  – 30 seconds under 100 rpm
- Slow Mix
  – 10 minutes under 30 rpm
- Settling
  – 30 minutes under 0 rpm

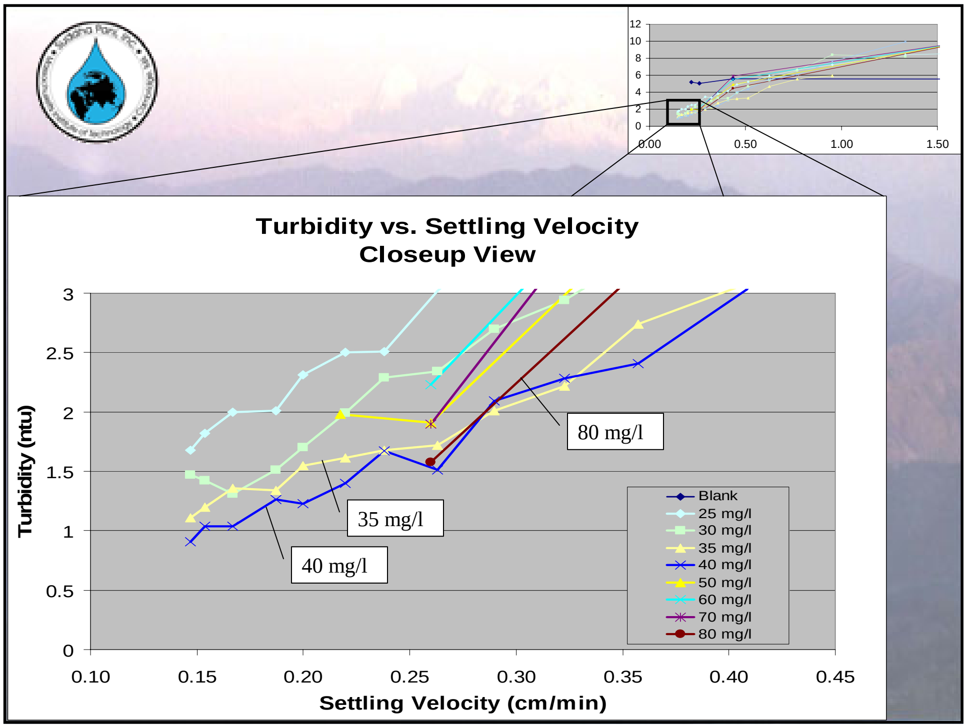
Analysis of Jartest Data

- Percent Removal of Turbidity
  - using “raw” water as control
  - using “zero” water as control
- Final Turbidity after Settling
- Settling Tests



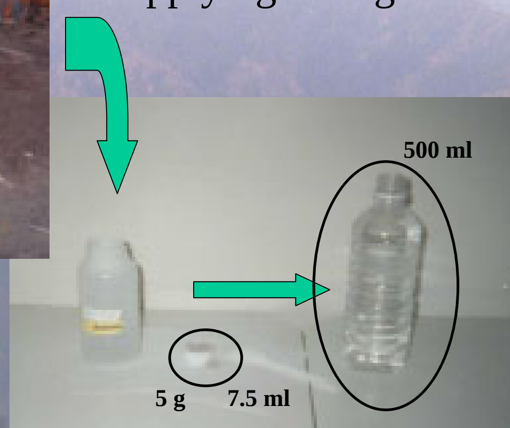

Final Turbidity vs. Dosage
Final Turbidity (ntu)
Dosage (mg/l)
Alum - Bansbari
Alum - Mahankal
Alum - GAC
FeCl3
0
1
2
3
4
5
6
7
8
9
10
0
10
20
30
40
50
60
70
80


Turbidity vs. Settling Velocity
Turbidity (ntu)
Settling Velocity (cm/min)
Blank
25 mg/l
30 mg/l
35 mg/l
40 mg/l
50 mg/l
60 mg/l
70 mg/l
80 mg/l
0
2
4
6
8
10
12
0.00
0.50
1.00
1.50
2.00
2.50



Manual Coagulation

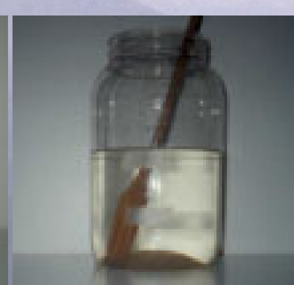
Applying 40 mg/l dose



Water Treated through Manual Coagulation

- 30 seconds under ~ 1.5 rotations per second
- 10 minutes under .5 rotations per second
- 30 minutes under 0 rotations per second

Water Treated through Manual Coagulation



Raw Water

Coagulation Regime

Settling Time

0 min

Settling Time

30 min

Conclusions

- Optimum Dosage: 40 mg/l
- Point of Use Applications
  - incomplete color removal
  - turbidity removal much better in filters
  - disinfection requirement
- Filters cannot be discounted.

Filtration Study

Junko Sagara

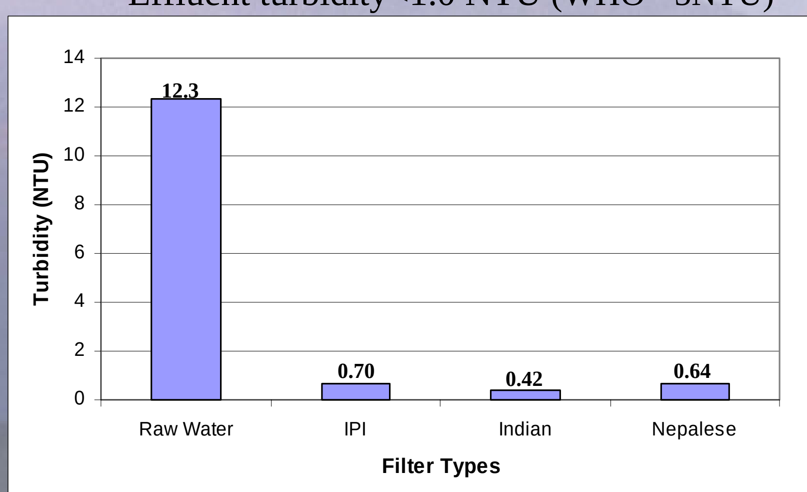
Indian Ceramic Candle Filter

Nepalese Ceramic Candle Filter

Industry for the Poor (IPI) Purifier

Test Results

- High turbidity removal efficiency
  - Effluent turbidity<1.0 NTU (WHO - 5NTU)



Microbial Tests

- HACH P/A Test
  - Total Coliform and *E.Coli*

Filter	Total Coliform	*E.Coli*
IPI Purifier (no Cl)	+	+
IPI Purifier (with Cl)	-	-
Indian Filter	+	-
Nepalese Filter	+	+

- HACH MPN Test
  - H_2S Producing Bacteria
  - Similar Results Obtained

Availability of Filters

- Industry for the Poor Purifier
  - Chlorine bleach not available in Nepal
  - Sediment and activated carbon filters expensive in Nepal
- Indian Ceramic Filter
  - Widely used in Nepal among families with higher income
  - Price too high for lower income families or people in the rural areas (US$10 to US$20)
- Nepalese Ceramic Filter
  - Very cheap (US$3)

Recommendation and Conclusion

- The Point-of-Use Filtration systems tested achieved:
  - High turbidity removal efficiency
  - Inadequate removal of microbiological contamination
- Filter systems tested do not treat water to an acceptable drinking water quality
- Nepalese Ceramic Candle Filter with Disinfection is recommended
  - Colloidal Silver Disinfection

Disinfection Study

Amer Khayyat

Disinfection Study

- Three disinfection techniques studied and tested for possible Point of Use (POU) application
  - Chlorination
  - UV disinfection
  - Solar Disinfection

Selection Criteria

- Efficacy: Study local performance and compare with Laboratory and Literature Benchmarks
- Cost: Must be affordable to the lower income brackets; those less likely to have safe water
- Equipment: Focus what is locally produced/available
- Regulatory: Compliance with national sanitation and pollution policies
- Socio-cultural: Acceptable to local traditions, customs and cultural standards

Chlorine Disinfection

- IN THEORY
  - Advantages:
    - inexpensive.
    - widely available
    - proven effectiveness
  - Disadvantages
    - Trihalomethanes (carcinogenic)
    - Requires supply of chemicals and relatively accurate dosages
    - Bad taste which may be unacceptable
- IN PRACTICE
  - Advantages:
    - proven effectiveness in municipal applications.
  - Disadvantages:
    - Is NOT locally available in retail outlets; even municipal supplies intermittent
    - High sensitivity to chlorine taste and smell
    - Turbid/Organically contaminated sources heighten THM risk

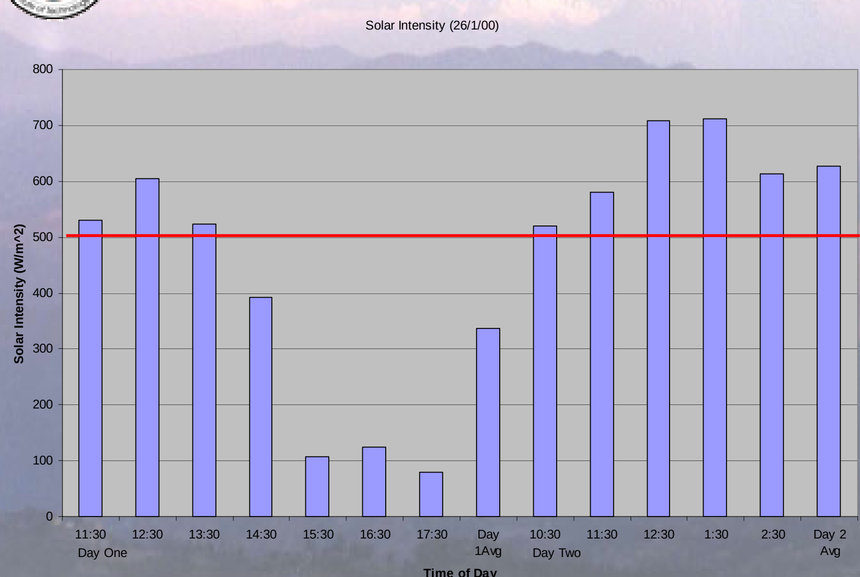
Ultraviolet Disinfection

- Advantages:
  - None to speak of in the context of this study
- Disadvantages:
  - Available locally as a proprietary imported luxury item
  - Electric grid highly limited
    - 14 % of all households
      9 % of all rural households
      (UNDP HDR 1998)
  - Water turbid esp. in the Monsoon season

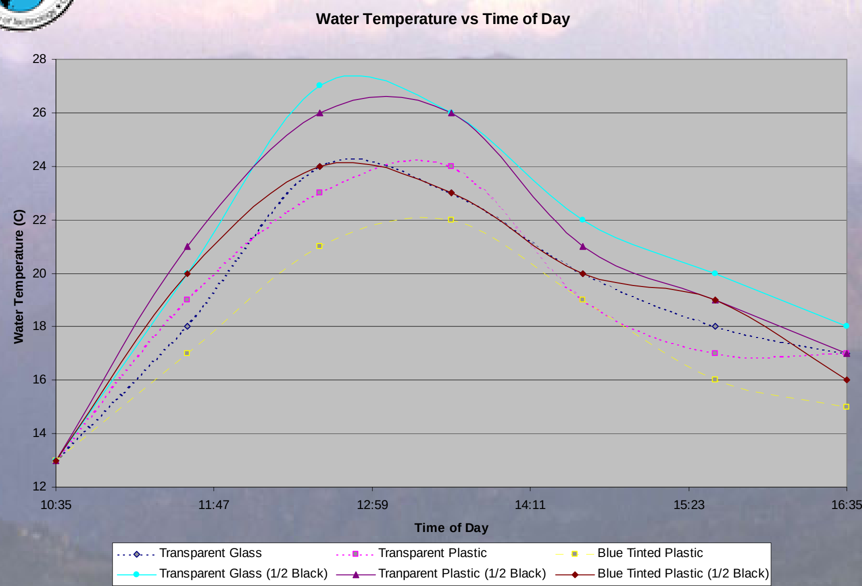
Solar Disinfection

- IN THEORY
  - Advantages
    - Free, no equipment and powered by the sun
    - Good efficacy in sunny regions
  - Disadvantages
    - Dependent on climate, temperature and water conditions
    - hard to test for efficacy
    - still not fully studied
- IN PRACTICE
  - Advantages
    - Plastic and Glass bottles widely available
    - Public appeal
    - At worst will not decrease water quality
  - Disadvantages
    - No data available on solar radiation
    - Turbid water and low sun during monsoon
    - No residual
    - Large possibility for human error

Solar Disinfection



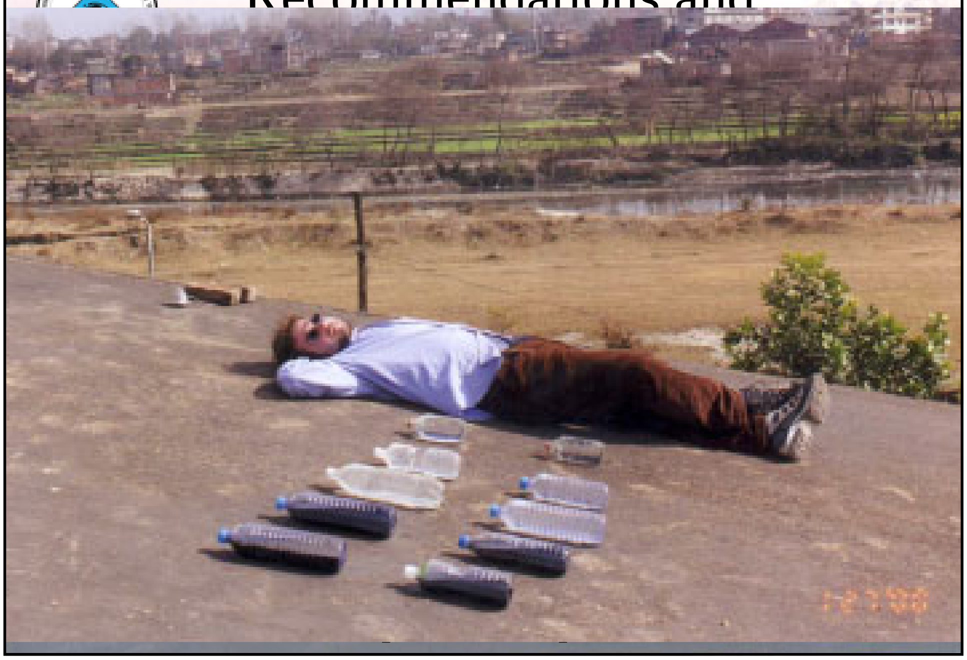
Solar Disinfection



Solar Disinfection

P/A test			
Before			
Total Coliform	Positive		
E-Coli	Positive		
After	**Untinted Plastic**	**Untinted glass**	**Blue Plastic**
Total Coliform	Negative	Negative	3 Positive 1 Negative
E-Coli	Negative	Negative	Negative

Recommendations and



Economics and Logistics of Point-of-Use Filters

Benoit Maag

Purpose : To find ...

- Who needs POU ?
- Who can afford POU ?
- What are the existing products ?
- How to expand use ?

POU = Point-Of-Use Treatment

Who needs POU ?

- Mountain areas : No
- Populated Rural Areas : Yes & No
  - No centralized system
  - Contaminated Water
  - Sanitation first ?
- Urban areas Yes
  - Poor centralized system
  - Contaminated water
  - Many people boil and/or filter

Who can afford POU ?

- Populated Rural Areas : 10 % pop. ?
  - Affluent families
- Urban areas < 30% ?
  - Estimates range from 30 % to 90 %
  - Affluent families

What are the products ?

- Standard design <-> Mature market
- Indian-made ceramic candle metal filters
  - 600 ~ 1200 Rs / filter (13 ~ 30 liter capacity)
  - 80 ~ 100 Rs / candle (1~4 candles per filter)
    - Need to be cleaned and replaced regularly (every 2 months ?)
    - 40 ~ 200 Rs / month
  - vs :
    - Average income : 1000 Rs / month (Nepal average)
    - Kerosene : 45 Rs/month (5 liters / day)
    - Chlorine : 20 Rs / month (5 liters / day)

US Equivalent

$ 2000 per filter

$ 200 /mo for candles

What are the products ?

- Problems :
  - Small capacity
    - 5 liters / day / candle -> water for 2-3 people
  - Clogs with turbid waters (rainy season)
  - No disinfection
  - Candles are easily breakable
  - Candle fixture leaks often
  - Expensive

How to expand use ?

- A better product is necessary
  - A reliable system at current prices would be well accepted
  - Price is far too high for most people
- Distribution ?
  - Accurate
- To expand use beyond the affluent
  - Sponsor ?
  - Who will be the ‘Social Carrier of Technology’ ?

Social Carrier of Technology ? A difficult and controversial issue

• Market	Limited
• Government, Foreign Aid, NGOs – Work on large/medium scale projects	No
• Para-Government (Schools, Health posts...) – Limited staff, money and few incentives	No
• Humanitarian, Religious, Political groups – Usually high motivation but limited scale	Limited

Conclusions

- POU is needed
- Mature market
- Distribution is OK
- Standard products are expensive and perform poorly

- A reliable product is needed
- Expanding use to the majority is difficult
  - Cost
  - Social carrier of Technology