Engineers Without Borders Bristol & Frank Water

Alternatives to Reverse Osmosis for Defluoridation of Drinking Water in India

September 2013

Contents

1. Introduction

The Problem: High fluoride content in water

In the region of India that Frank Water works in there is particularly high fluoride content in the groundwater for geological reasons, but groundwater sources are preferable to surface water sources due to the pollution from industry etc. in the area. Long term use of this high fluoride groundwater as drinking water leads to fluorosis, which attacks the joints in the body. Fluoride is a salt and therefore a very small soluble particle, this makes it difficult to remove from the water and means the options for treatment are limited.

Current technology

The current FRANK Water system is very thorough in treating the water: it is made up of multi-stage filtration, pre and post-treatment, and reverse osmosis. Reverse osmosis is particularly problematic as it produces very high quality water though at high operating cost, meaning it is sometimes too expensive for everyone in the affected area to have access to it.
The current water treatment technology that Frank Water implement is well demonstrated in this video: http://vimeo.com/49666059.

Reverse Osmosis (RO):

Advantages	Disadvantages
✓ Proven technology	✗ Relatively high capital costs
✓ Removes chemical and biological contamination to WHO standards	✗ High ongoing operation and maintenance costs
✓ Recognised & desired technology communities – 'willingness to pay'	✗ High volumes of waste water – up to 2/3rds wasted
✓ Widespread implementation – supply chain and operational benefits	✗ Heavily contaminated effluent

Table 1: Advantages and Disadvantages of Reverse Osmosis (RO)

The Project

FRANK Water have worked with Engineers Without Borders Bristol to undertake an investigation into improving the water processing systems they deliver to communities in India. This report is the culmination of the work to date, and outlines the alternative technologies for defluoridation that FRANK Water may fund in the future.

Alternative Solution Characteristics

The alternative solution should:
- Be desirable to users
- Have affordable capital costs
- Have affordable recurrent costs (less energy intensive than RO)
- Be operable and maintainable by the community
- Be physically robust
- Be less wasteful

2. Alternative Defluoridation Technologies

A number of alternative technologies for defluoridation have been investigated, these are:
- Clay and Soil
- Bone Char
- Contact Precipitation
- Nalgonda Technique
- Activated Alumina
- Rainwater Harvesting

Each of these technologies are discussed in detail in this chapter. For each technology an overview is given, as well as a technical explanation of how it works, the advantages and disadvantages, a case study example, an overview of maintenance requirements and scalability, and an estimate of capital and operating costs.

2.1 Clay and Soil

Summary
Clay/soil has successfully been used as a method for removing fluoride from drinking water in domestic dwellings but it has not been used on a larger (village) scale. Many different forms of and differently treated soils and clays have also been tested in a laboratory setting for their removal capacities; they can be effective fluoride removers at lower raw water concentrations of fluoride but their effectiveness in situ has not been widely tested. The advantages of this treatment method are the low cost, ease of construction and ready availability of materials; the disadvantages are variable efficacy of the wide variety of media and the unproven scalability.

Summary of technology

How it works – removal unit

Raw water flows through a bed of clay/soil and the fluoride is accumulated in a thin layer on surface of the clay/soil (see also figure 1?).

How it works - mechanism

Sorption is a physical/chemical process where one substance becomes attached to another, in this case the fluoride ions to the clay/soil media.
For clay/soil, the main sorption mechanism is thought to be ion exchange (Coetzee et al., 2004), where, for example, OH^- ions are released when F^- ions are adsorbed to the clay. Different soils and clays have different fluoride sorption levels and factors include: pH, clay surface area, structure, aluminium content, the presence of exchangeable cations which can form fluoride precipitates (Ayoob et al., 2008). Other adsorption mechanisms exist and could contribute (research is ongoing): physical (van der Waals forces - fluoride weakly held), chemical (fluoride strongly held) or electrostatic (attraction to charged surfaces). Laboratory tests have been carried out on many types of clay and soil to gauge removal capacities (for a review see Jagtap et al. (2012) or Bhatnagar et al. (2011)).

Problems

The technology is simple. The problems are: ensuring a supply of effective media; that the unit becomes less effective with time and so the media need replacing after about 1 month (packing is difficult – see case study); that the technology has previously been used at house and not village scale.

Case Study: Sri Lanka

The WHO supported a successful project in Sri Lanka in which 1400 households in 60 villages participated (Coetzee et al. 2004). Fired brick (calcined clay) is used for fluoride removal in domestic column units (charred charcoal and pebbles are layered on the top and water is passed upwards through the unit). The system is shown in figure 1; the bricks are broken to a size 8-16mm and they are packed to a height of 75cm. The efficiency depends on the "quality" of the burnt bricks. The unit can be used for 25-40 days, the withdrawal of water was 8 litres per day and the raw water fluoride concentration was 5 mg/l[1] (Lyengar, 2001); the average fluoride level in the treated water was 1 mg/l and the cost per defluorider was estimated at US$1-5 (depending on how much 2nd hand material was used) (Chibi and Haarhoff, 2000). There is no attempt made to regenerate the media because it is not cost effective. The main practical problems at this scale are packing the columns and controlling the flow (Ayoob et al. 2008).

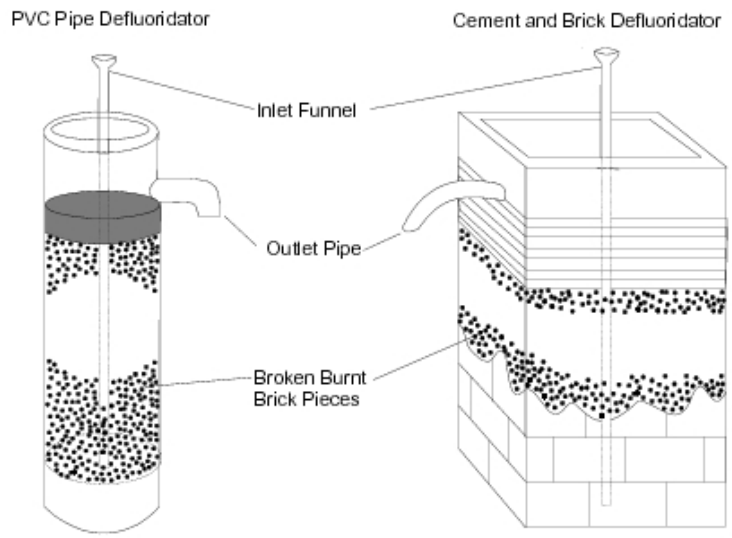

Figure 1. Design of the clay and soil defluoridation unit used in Sri Lanka

Scalability and Ease of Maintenance

This seems to be where the major issue lies with this technology. It is proven at household scale but it is not clear how it could be scaled up to village scale. The technology is simple but maintenance would need to be ongoing: it is possible that the most effective long-term implementation would be for the village to take ownership, however it depends on the model that FRANK Water and the partner organisation are comfortable with and agree on.

Approximate Costs

Using the information we have from the case study we assume: an 8 litres per day defluorider can be used for 30 days and costs $1-5 after which time it is replaced/refilled/regenerated at a cost of $1-5. 8 l/day = 1/3 l/hr; scaling up to 500 l/hr requires 1500 defluoriders at a cost of $1500-7500 per month; similarly 1000l/h requires 3000 defluoriders at a cost of $3000-15000 per month. Obviously we've made sweeping generalisations and massive assumptions here – but "low cost" water seems to be expensive (perhaps the refill/regeneration is much cheaper than assumed).

[1] This is a similar concentration to the source water levels given to us for Nizamabad, which are between 2 and 4.5ppm.

From this methodology we can complete the metric table to aid comparison to other technologies:

Metric	Source: (Chibi and Haarhoff, 2000)
Number of people provided for/volume treated	1000l/hr
Initial capital costs	$3000-15000
Short(day)/medium(month)/long(year) term replenishment costs	Monthly – replace media – fire some clay/soil – whatever that costs – depends on availability
Additional costs (labour/preprocessing)	Labour intensive – 3000 deflouriders needed to be maintained

Table 2: Estimated Costs for Clay and Soil

References: Clay and Soil

- Ayoob, S., A.K. Gupta and V.T. Bhat, 2008, "A conceptual overview on sustainable technologies for the defluoridation of drinking water", Critical Reviews in Environmental Science and Technology, 38, 401-470
- Bhatnagar, A., E. Kumar and M. Sillanpää, 2001, "Fluoride removal from water by adsorption – A review", Chemical Engineering Journal, 171, 811-840
- Chibi, C. and J. Haarhoff, 2000, "A promising approach to fluoride removal in drinking water supplies", Proceedings of the WISA Biennial Conference, Sun City, South Africa, 28 May – 1 June
- Coetzee, P.P., J. Haarhoff and C. Chibi, 2004, "Removal of fluoride from drinking water with clay-based defluoridators", technical report no. 1289/1/04 prepared for the Water Research Commision, ISBN 1 77005 024 8
- Fawell, J., K. Bailey, J. Chilton, E. Dahi, L. Fewtrell and Y. Magara, 2006, "Fluoride in Drinking-Water", WHO.
- Japtap, S., M.K. Yenkie, N. Labhsetwar and S. Rayalu, 2012, "Fluoride in water and defluoridation of water", Chemical Reviews, 112, 2454-2466
- Lyengar, L., 2001, "Technologies for fluoride removal, in Small community water supplies: technology, people and partnership", technical paper edited by J. Smet and C. van Wijk, published with financial support from the Ministry of Housing, Spatial Planning and the Environment in the Netherlands.
- Padmasiri, J.P. 1995, "Low Cost Fluoride Removal by an Upward Flow Household Filter", Water
- Supply, Vol. 13, Nos. 3/4, Osaka.

2.2 Bone Char

Summary

- Bone Char method of defluoridation involves ion exchange of fluoride ions (in water) and hydroxide ions (in charred bone material).
- Can achieve high fluoride reduction, e.g. high concentration of 23mg/l reduced to WHO standard of 1.5mg/l.
- Bone material becomes saturated after approximately 1.5months of use (though this is dependent on concentration of fluoride and volume of water treated, and in many cases in case study was still reducing fluoride to within WHO standard for 5 months), and requires regeneration - see contact precipitation method.

- Potential issues with cultural acceptance of technology as it is using dead animal bones. Though this was less of an issue than anticipated in case study of Ethiopia, may be an issue in India due to use of cattle bones being unacceptable to Hindu beliefs. Fish bones have been found to work well and therefore may be an option (ref?)
- Charring process of the bone material requires high temperature furnace and high level of control to achieve results.
- Also removes arsenic from water

Technically How it Works

Fluoride ions are the same charge and size as hydroxide ions and these can therefore replace each other in mineral structures. The main mineral present in animal bones is hydroxtapatite which contains hydroxide ions and therefore fluoride can easily be incorporated into bones, replacing these hydroxide ions.

The bone char method involves firstly processing the bones, by grounding and then charring in a controlled furnace (operating at approximately 600°C(ref?). Charring bones removes organic material, avoiding issues of bad taste and colour of water after treatment process, and leaving a large surface area internally where the processes can occur. Charring in a furnace is sometimes a highly controlled environment (example case where temperature is raised at 4°C/minute then held at 600°C for 4 hours, also quoted as optimally 550°C for 4 hours (Sorlini et al, 2011)) but can also be achieved in less technically vigorous furnaces/kilns at temperatures of 350-400°C, as seen in the African Rift Valley (Korir et al, 2009). In some situations where the high precision furnace wasn't implemented, there were issues with colour of treated water, and although the fluoride removal was effective, the water was not accepted by the community: a 1000 l/day system implemented in Langano, Ethiopia successfully reduced fluoride level from 9mg/l to 0.9 mg/l, but the treated water was not accepted by the community due to the colour (Abaire et al, 2009), however there are many examples of less technically advanced kilns/furnaces successfully providing water (Arrenberg, 2010). ?

Using this method with groundwater is appropriate however using lake-water resulted in bad taste and odour because of the higher microbial activity in surface water.

Bone char becomes saturated but works well for defluoridation for approximately 1.5 months even with exceptionally high concentrations of fluoride (23mg/l), and in many cases fluoride is still reduced to within WHO guidelines for up to 5 months of use. Typically reliably removes 1.2 (+/-0.3) mg F/g bone char filter material both in laboratory and field tests (Mutheki et al, 2011).

WHO guideline safe limit for arsenic is 0.01mg/l and excessive levels of arsenic can lead to significant health issues including liver and skin cancer, circulatory disorders, hyper pigmentation, and skin lesions. Bone char can remove arsenic as well as fluoride from water. A study (Brunson & Sabanti (2009)) investigated the effectiveness of fish bones, rather than cattle bones which have typically been the material used in bone char treatment case studies to date. The fish bones were charred in furnaces at a range of temperatures for arsenic and fluoride removal. Fish bones burned at 500°C were found to be most effective in terms of removal rate and aesthetic considerations. Specific to this project, this could also be beneficial as it avoids the use of cattle bones which is likely to be an issue for those of the Hindu religion which is predominant in India.

Advantages of bone char in comparison to the alternative defluoridation technologies are that it requires no daily dosage of chemicals, has a high removal efficiency, the technology is easy to construct and manage, and the materials are cheap and widely available (Arrenberg, 2010).

Problems

The main technical issues with bone char are the lifespan of the filter before becoming saturated, the required regeneration of the bone material, and sourcing appropriately treated bone material from an appropriate high temperature controlled furnace.

The main (perceived) social issues with bone char are the use of cattle bones, and the labour required. (Ethopia case study - religious and cultural beliefs: success dependent on elders saying its a harmless non-living item that can be used even in fasting periods.)

Case Study: Ethiopia (Rift Valley)

Defluoridation in area using activated alumina community filters from as early as 1962, however not in continuous operation due to technical problems and limited supplies of AA (Esayas et al, 2009). Nalgonda also implemented but not in use due to various technical, financial and social challenges.

Challenges in the area include very high fluoride concentration (ranging from 3 mg/l to 23 mg/l), and doubts over acceptability of bone char due to religious and cultural beliefs. The pilot scheme implemented household scale bone char filters consisting of 20l plastic buckets with lids and taps, filled with 8kg of bone char that required 20 minutes contact time before treated water was removed.

The scheme monitored the results and community uptake of the bone char filters, and found that after 12 months only half of the households still used the filters. 33% complained of bad taste and/ or odour, though investigations concluded that these odour/taste issues were due to treating organic rich, highly-turbid lake water and were not present in groundwater treatment.

The preconceived social issues of acceptability of bone char due to religious beliefs proved to be incorrect: religious leaders accepted the use of charred animal bone. Filter efficiency is high and capable of producing WHO compliant fluoride levels even in concentrations of fluoride > 20mg/l. However, the lifespan of the bone material is limited and saturated material requires regeneration or replacement: typical lifespan of 2-3 months, though 61% filters still WHO compliant after 5 months without regeneration.

Scalability

Applied at a household level each filter consists of a 20l plastic bucket with 8kg of bone char (Esayas et al, 2009). Also seen at community scale (up to 5,000l) in Kenya (Mutheki et al, 2011). Works most effectively in terms of fluoride removal and treated water quality when used daily rather than as a discontinuous process (Sorlini et al, 2011).

Maintenance

A conservative estimate for the lifespan before saturation of bone material is approximately 1.5 months of use, though this is dependent on concentration of fluoride and volume of water treated, and in many cases is seen to still reduce fluoride to within WHO standard for 5 months. After this time the bone material requires regeneration - see contact precipitation method, or replacement with more bone char material for the filter to continue to operate effectively.

Costs

Metric	Source: Arrenberg 2010
No. of people provided for / volume of water treated	8,333 litres (5000kg bone char produced: 0.6kg/l) 30 day batch process
Initial capital costs	Low tech community kiln: Thermometer, iron roller, sieve system, monitoring equipment, plus construction materials and labour = approximately US $2570 OR Small scale private enterprise: Larger kiln (US$6170) plus mechanised crusher, mechanised sieve, lab facilities (US$4600) and vehicle
Short (24h), Medium (1 month), & Long term (1 year) operation/maintenance/ replenishment costs	Per batch (30 days): Materials:10000kg bones, charcoal, sodium hydroxide for washing, US$900 Electricity for mechanised processing, US$316
Additional costs e.g. labour/ pre-processing	Labour: 5 workers for 30 days (including other operations) US $392

Table 3: Estimated Costs for Bone Char Technique

References: Bone Char

- “Production models for bone char defluoridation, Naivsha, Kenya” A. Arrenberg, Cranfield University, 2010
- “Operational experiences on small-scale community defluoridation systems” B. Abaire, F. Zewge & M. Endalew, Ethiopia WEDC conference, 2009
- “Sustainable use and implementation of bone char as a technology for arsenic and fluoride removal” L.R. Brunson & D.A. Sabatini, 2009
- “Household water treatment: Defluoridation of drinking water by using bone char technology in Ethiopia” S. Esayas, M. J. Mattle & L. Feyisa, Ethiopia WEDC Conference, 2009
- “The development of bone char based filters for the removal of fluoride from drinking water” H. Korir et al, WEDC Conference, 2009
- “Comparative performance of bone char-based filters for the removal of fluoride from drinking water” P. M. Mutheki, et al, WEDC Conference, 2011
- “Experimentation on bone char-based treatment for fluoride removal from drinking water in Senegal” S. Sorlini, & D. Palazzini, Italy, WEDC Conference, 2011

Questions and Further Work

This technique is specifically for defluoridation (and arsenic removal) - using ion exchange - whereas RO is a broader brush in terms of water purification. Bone char may therefore need to fit inside a system that takes care of other water pollution/quality issues too.

2.3 Contact Precipitation (Nakuru Technique)

Summary of the Technology

Bone char has been used for water purification since the 1940s[2], but in the early 1990s contact precipitation was developed to increase the life span of bone char removal by introducing more calcium and phosphate into the water. Pellets have been developed by the Catholic Diocese of Nakuru (CDN) (*place?) to conveniently introduce these chemicals[3].

The process seems to be promising, because it implies:

- relatively low daily working load;
- high reliability without the need of surveillance of flow or effluent concentration;
- high removal efficiency, even in case of high raw water fluoride concentrations;
- low operating cost; and
- no health risk in the case of misuse or over-dosage of chemicals.[4]

Technically How it Works

In contact precipitation, Calcium Chloride and Monosodium Phosphate are introduced to the water to produce Calcium Fluoride and Fluoroapatite as precipitates which can then be filtered through a contact bed of Bone Char (considered a necessary catalyst) which increases the rate of precipitation. The chemical processes undergone in contact precipitation are not fully understood at present. The efficiency of precipitation depends on pore water velocity and filter contact time.

The plants comprise a column, containing a relatively small, saturated bone charcoal contact bed. Gravel, or coarse grained bone charcoal, is used as a supporting medium. Above the bed a relatively large space is used for mixing the chemical with the raw water. From the bed the defluoridated water flows continuously by gravity to a shallow, but wide, clean water tank. One or more clean water taps are fitted at the bottom. The flow from the raw water tank to the clean water tank is constrained by a valve or a narrow tube arrangement to allow for appropriate contact time in the bed. Too short contact time would reduce the removal capacity and increase the escape of chemicals in the treated water. Too long contact time may result in precipitation of calcium phosphates in the upper parts of the filter bed, thus also reducing the removal efficiency. The optimum contact time is not yet known but contact times of 20 to 30 minutes have been shown to produce excellent operation. The filter resistance is negligible compared to the flow resistance through the tube and/or the valve (Dahi, 1998).

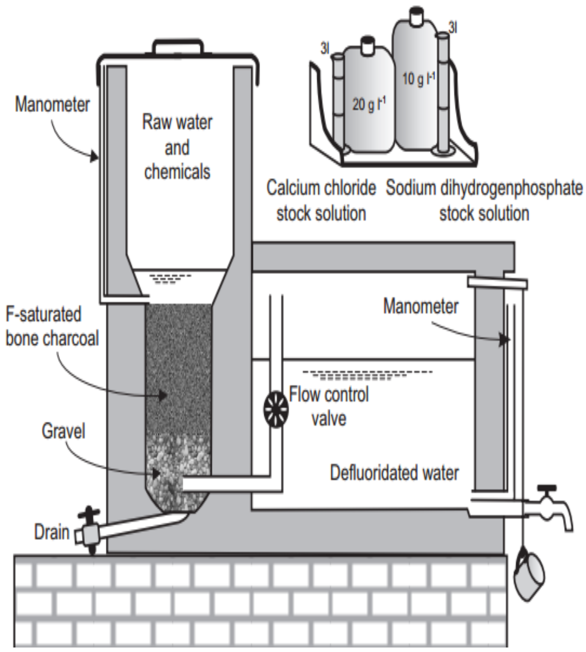

Figure 2: Schematic of Contact Precipitation of Fluoride in Ngurtodo[5]

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[2] Swiss Federal Institute of Aquatic Science and Technology 2008 Annual Conference - http://www.northsouth.ethz.ch/news/past_events/ann_conf_08/WPQ3_Osterwalder.pdf

[4] List from http://www.who.int/water_sanitation_health/publications/fluoride_drinking_water_full.pdf

[5] http://www.who.int/water_sanitation_health/publications/fluoride_drinking_water_full.pdf

This process works most effectively with fresh bone char, with char already fluoride saturated it can fail to reach WHO standards.
Pyrolysis (burning without oxygen) is considered the method which produces the highest quality bone char but is more energy intensive and therefore more expensive than other charring methods. However, the adsorption capability is less relevant to the production of bone char used for contact precipitation, hence it is suggested that bone char for contact precipitation could be simpler and cheaper to produce. Research has suggested that the more calcinated method (http://de-fluoride.net/2ndproceedings/90-93.pdf) for producing bone char is actually more effective for contact precipitation.

Potential Problems

- If the bone char has not been correctly heated there can be issues with taste and smell which means some projects fail when a suitable source cannot be found[6]
- It has been found that the Nalgonda process isn't working as it requires community engagement. Hence the same problem could occur with contact precipitation.
- An article reviewed cites bone char working when implemented at a household level, perhaps this is the scale required with materials supplied.[7]
- For contact precipitation to be effective (relative to bone char), at high concentration, low flow rates must be used.[8]
- The contact precipitation process also produces sludge which must be appropriately disposed of.
- Past a certain point in concentration the precipitation method is unable to remove further fluoride from the water and more waste matter is produced, however using greater quantities of calcium and phosphorous can increase the capability of the filter.
- Lower flow rates and increased quantities of calcium and phosphorous also increase the lifecycle of the filter before it has to be regenerated or replaced.
- A trained individual is required (in case study projects, a village member has been successful) to test water quality after a certain time period for fluoride level, otherwise materials would have to be replaced at a conservative rate.

Case Studies

Several relevant case studies have been found for comparison, which are as follows:

1. The Ngurdoto primary school, supplying water from a single system to 500 people during school hours, community maintained.
2. Kenyan Rift Valley, Nakuru – possibly the first case of contact precipitation implemented, multiple articles and studies refer to this case
3. Laboratory tests – a range of lab tests have been carried out on various concentrations, time periods and process methods which provide the options which will bring the water within WHO standards including the most efficient and most effective.

The references provided alongside the figures link to the original case studies considered for further reading.

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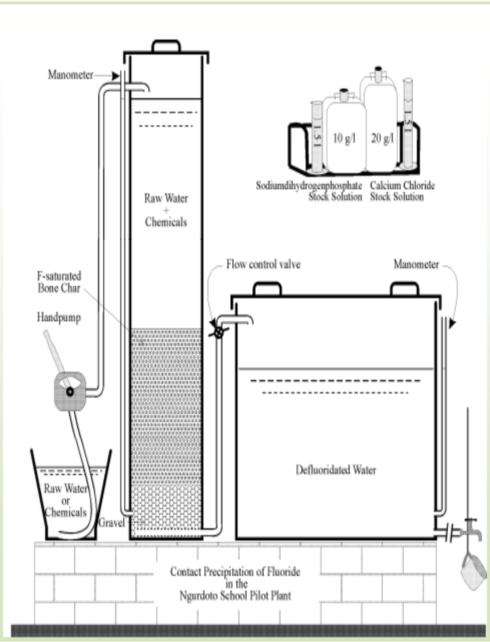
[6] Groundwater Management in Asian Cities: Technology and Policy for Sustainability, Satoshi Takizawa, Springer, 2008. (also a general text reference)

[7] http://icoh.anamai.moph.go.th/eng/Interesting%20topics/solving_flu_prob/4th/presentation/pdf/household%20bone%20char%20defluoridated.pdf

[8] http://www.eawag.ch/medien/veranstaltungen/events/geogen2013/presentations/Esther

Ngurdoto Case Study



Provides drinking water for about 500 people during school hours. The chemicals were added daily and mixed with the raw water. After mixing the water was allowed to flow at a declining slow rate through the saturated bone char compartment to a large clean water tank. Need to fetch the water in buckets every morning. One and half litres of each of the two stock solutions containing Ca and PO4 are pumped to the raw water column after mixing with the raw water from the first two buckets. The remaining water is then pumped to fill the raw water column, in total about seven buckets. As raw water is falling into the raw water column, the supernatant water is completely mixed. The flow control valve is then opened, but only to allow slow flow through the contact bed, the average filtration velocity not exceeding 1m/hour. A water sample is taken for testing. This procedure is carried out once a day.

Figure 3: Ngurdoto School Contact Precitation Defluoridation Unit - Image and Text[9]

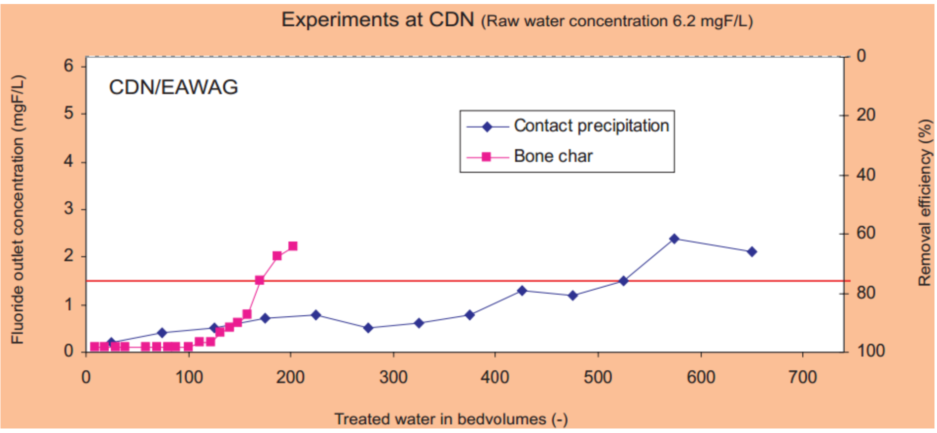


Figure 4 [10] : Experimental Testing Comparing Contact Precipitation and Bone Char Techniques

TABLE 2. Residual fluoride concentration in jar test, where water containing 13 mg F/L is added different media with and without dosage of calcium and phosphate. Dosage of medium 100 mL/L. Contact time is 2 hours, stirring 140 RPM.

Batch	Medium	$CaCl_2 \cdot 2H_2O$*	$CaHPO_4 \cdot 2H_2O$	Residual F^-, mg/L
0	Not added	Not added	Not added	13.0
1	Not added	159 mgCa/L	226 mgPO_4/L	12.8
2	Marble	159 mgCa/L	226 mgPO_4/L	13.0
3	Quarts sand	159 mgCa/L	226 mgPO_4/L	12.2
4	Fresh bone char	159 mgCa/L	226 mgPO_4/L	0.3
5	Saturated bone char	Not added	Not added	14.1
6	Saturated bone char	159 mgCa/L	226 mgPO_4/L	3.2

* The dosage of calcium is calculated as the sum of calcium originated from calcium chloride + the calcium originated from calcium monohydrogen phosphate.

Figure 5: Comparison of Variations of Contact Precipitation Method with Different Mediums [11]

[9] http://de-fluoride.net/2ndproceedings/128-137.pdf taken from paper http://wedc.lboro.ac.uk/resources/conference/22/Dahi2.pdf

[10] Swiss Federal Institute of Aquatic Science and Technology 2008 Annual Conference - http://www.northsouth.ethz.ch/news/past_events/ann_conf_08/WPQ3_Osterwalder.pdf

[11] http://de-fluoride.net/2ndproceedings/128-137.pdf

Scalability
Case studies of implementation at village level but it's suggested that the process could be implemented at virtually any scale, with different material quantities required for different residual fluoride concentrations (studies reference slightly varying quantities, with suggestions of a trained individual in the community to test the water quality).

Ease of Maintenance
To provide extra calcium and phosphate virtually any chemical compounds can be used as long as they are dissolved prior to mixing in with the water but both solutions should not be mixed together in advance to prevent precipitation of calcium phosphate.

Cost: Capital & O&M
The tables below show estimates of cost for the process from different sources, the first applies to the European market but givens specification of the main considerations for different areas below:

Table 2. Estimated running costs for chemicals purchased in large quantities in Europe

Transportation and equipment costs are not considered. The unit price and the residual fluoride concentration are estimated for 10 mg/l initial fluoride concentration.

Treatment Method / Chemical Used	Formula	Price* US$/ton	Dosage g/m3	Residual Conc. mg/l F-	Unit Price US$/m3
Nalgonda					
Aluminium Sulphate (Alum)	$Al_2(SO_4)_3 \cdot 18H_2O$	468	812	2.0	0.44
Calcium Oxide (Lime)	CaO	283	219		
Bone Char**		333	2300	0.8	0.76
Contact Precipitation					
Calcium Chloride (CC)	$CaCl_2 \cdot 2H_2O$	283	333	0.4	0.22
Sodium Dihydrogen Phosphate (MSP)	$NaH_2PO_4 \cdot H_2O$	780	167		

* Amount of 10 tons or more, purchased from Kemira LTD, in Sweden.
** The given price for bone char is from China.
Bone char from UK and Tanzania apparently cost much different, 2280 and 167 US$ /Ton respectively.
The fluoride removal capacity of bone char is assumed to be high; 4 mg/g.

Table 4: Contact Precipitation Cost Comparison - Europe [12]

Below is the second table, this one is for Ethiopia, again a very different location:

Table 1 Budget for three different consumption scenarios (ETB = Ethiopian Birr)

		Scenario 1	Scenario 2	Scenario 3
Raw water consumption in future (m^3/month)		250	250	250
Treated water consumption in future (m^3/month)		75	50	25
Estimated running period		May 10 - Jun 12	May 10 - Dec 12	May 10 - Jul 14
Income, ETB	Raw water point 1)	53,000	65,000	130,000
	Community filter	27,000	27,000	27,000
Expenditures, ETB (Community filter)	Amortization 2)	21,700	26,700	42,500
	Filter media 3)	17,500	17,500	17,500
	Raw water 4)	10,700	10,700	10,700
	Maintenance 5)	7,800	9,600	15,300
	Caretaker 6)	6,500	8,000	12,700
	Monitoring 7)	2,000	2,500	4,500
	Total	**66,200**	**75,000**	**103,200**

1) Income from selling raw water during the community filter running period, 2) amortization of the community filter infrastructure, assuming a life span of 15 years, 3) assuming production in Ethiopia, including all raw materials, labour and infrastructure, not including administration costs of the producer, 4) raw water tariff, including pumping and maintenance of water system, 5) 300 ETB/month are thought to be sufficient, 6) common salaries are around 250 ETB/month, 7) sampling by the woreda water bureau every 3 months, estimated costs of 250 ETB per sampling

Table 5: Contact Precipitation Costs - Ethiopia [13]

12 http://wedc.lboro.ac.uk/resources/conference/22/Dahi2.pdf

13 http://rwsnforum.files.wordpress.com/2011/11/160-osterwalder-ethiopia-short-paper.pdf

The third is an EAWAG table of estimates, given in the more easily relatable USD, the breakdown of the cost can be found through the reference on the original EAWAG presentation. It is hoped that by comparing the three, a rough estimate of cost with approximate error can be found.

Estimated Total Expenditures

USD/m^3

Technology	**Case I** **5 mg/L F** **5,000 lpd**	**Case III** **10 mg/L** **2,500 lpd**
Activated Alumina	2.00	3.40
Aluminum Hydroxide	2.20	3.70
Bone Char	2.10	3.50
Nakuru Technique	1.90	3.30
Electro Coagulation	2.50	3.20
Nalgonda Technique	2.10	3.20
Reverse Osmosis	5.10	8.40

Addis Ababa: 0.10 – 0.65 USD/m^3

Berlin: 2.60 USD/m^3

Table 6: Contact Precipitation Cost Comparison - EAWAG (USD) [14]

2.4 Nalgonda Technique

Summary of the Technology

The Nalgonda technique was developed by the National Environmental Engineering Research Institute (NEERI) in India in the 1970s as a simple, low cost and easy to use method of water defluoridation. It is achieved by the addition of alum and lime to the contaminated water supply. This forms aluminium hydroxide ´flocs´ that precipitate out and can be removed by sedimentation. The fluoride ions are also removed as they are electrostatically attached to the flocs. The method was first used on the community scale in the town of Kathri in the Nalgonda district of Andhra Pradesh, India and is therefore referred to as the ´Nalgonda technique´.

Technically How it Works

The process is aluminium sulfate based coagulation-flocculation sedimentation, where the dosage is designed to ensure fluoride removal from the water. Aluminium sulphate ($Al_2(SO_4)_3$) is added to the water and is stirred until dissolved.

Dissolution of the Alum:

$Al_2(SO_4)_3\ 18H_2O = 2Al^{3+} + 3SO_4^{2-} + 18H2O$

Aluminium hydroxide micro flocs are produced (flocculation) instantly and gathered to make larger, easily settling flocs.

Aluminium precipitation (acidic):

$2Al^{3+} + 6H2O = 2Al(OH)_3 + 6H^+$

The fluoride ions are attracted to the flocs (coagulation):

$F^- + Al(OH)_3 =$ Al–F complex + undefined product

[14] http://www.eawag.ch/medien/veranstaltungen/events/geogen2013/presentations/lars2

As the addition of alum causes the solution to become acidic, lime is added to neutralize the acid:
$6Ca(OH)_2 + 12H^+ = 6Ca^{2+} + 12H2O$
The weight of the floc is great enough for the flocs to settle at the bottom of the container and therefore be separated from the water through sedimentation.

Case Study
The use of the Nalgonda technique has been broad on both the domestic and community level in India and central Africa. Specifically in the Andhra Pradesh region of India, UNICEF reported that all but 2 of the 86 plants are not working due to high O&M costs. **There are many examples of failed Nalgonda Technique projects, further research into the causes and potential solutions of this would be beneficial before making decisions about the suitability of the Nalgonda Technique.**

Problems
- Desalination may be necessary when the total dissolved solids exceed 1500 mg/l.
- Hardness of the raw water in the range of 200 mg/l to 600 mg/l requires precipitation softening and beyond 600 mg/l becomes a cause for rejection or adoption of desalination.
- Generation of higher quantity of effluent sludge compared to electrochemical defluoridation.
- The large amount of alum needed to remove fluoride.
- Careful pH control of treated water is required.
- High residual aluminium is reported in treated water by some studies.

Scalability
Figure 1 illustrates configurations of the Nalgonda technique from the domestic level to community water works level. At the community level, the Nalgonda process can be linked to a single tubewell using a “draw and fill” method. In larger systems (for instance where tubewells are linked to a distribution system) the Nalgonda Removal of Excessive Fluoride process can be incorporated into a treatment train using flash mixing before flocculation.

Ease of Maintenance
Skilled person needed due to the importance of mixing quantities and need for proper mixing to occur before coagulation. This a likely contributing factor to the failure of the non-operational plants mentioned above.

Cost: Capital & O&M
Annual cost (1991) of defluoridation of water at 40 litres / capita / day is Rs.20/- for domestic treatment. Rs.85/- for community treatment using fill and draw system based on 5,000 population with F levels of 5 mg/l. (Eswar & Devaraj, 2011)

References: Nalgonda
•“Water defluoridation: Field studies in India” Eswar, P., & Devaraj, C. (2011). INDIAN JOURNAL OF DENTAL ADVANCEMENTS .
•“Fluoride mitigation technologies in Andhra Pradesh- UNICEF BRIEFING PAPER”
•“Water Quality and Defluoridation Techniques” Bulusu, K.R., Nawlakhe, W.G., Patil, A.R. and Karthikeyan, G. 1993. Volume 11 of Prevention and Control of Fluorosis, Rajiv Gandhi National Drinking Water Mission, Ministry of Rural Development, New Delhi.
•“Fluorides in water, defluoridation methods and their limitations” Bulusu, K.R., Sundaresan, B.B., Pathak, B.N., Nawlakhe, W.G. et al., 1979. Journal of the Institution of Engineers (India, 60, 1–25)

•"Defluoridation using the Nalgonda Technique in Tanzania" Dahi, E., Mtalo, F., Njau, B. and Bregnhøj, H. 1996. Paper presented at the 22nd WEDC Conference, India, New Delhi, 1996.
•"Mitigation of Fluorosis in Nalgonda District Villages", A S Narayana, A L Khandare and M V R S Krishnamurthi, 4th International Workshop on Fluorosis Prevention and Defluoridation of Water

2.5 Activated Alumina

Summary of the Technology
Activated Alumina (AA) technology is an adsorption-based process. It is one of the most common adsorption technologies used for defluoridation and is regarded as one of the best technologies to remove fluoride from water to within WHO standards9i0-oooi[15].
Adsorption technologies are relatively simple and can be used for drinking water treatment in small communities due to the associated costs and operational requirements. In addition to removing fluoride, AA can also remove other toxic elements, such as arsenic and selenium [i],[16].

Technically How it Works
AA consists mainly of aluminum oxide, Al_2O_3, and it is presented as granular, highly porous material. The surface area per unit weight is normally in the range of 200– 300 m2?/g [17].
The major factors affecting fluoride removal are pH, surface loading (the ratio of total fluoride concentration to the alumina dosage), and presence of other interfering ions. Some researchers have reported an optimal pH of 5 for fluoride removal [iii].
The specific affinity of AA for fluoride coupled with excellent exchange capacity makes it an ideal candidate for defluoridation. The uptake capacity and reuse potential are considered important parameters for the application of AA for defluoridation in the field. Packed beds of granular activated alumina have been traditionally used for defluoridation of public water supplies, and their reported capacity is in the range 6750–11,760 g/m$^{3?}$in a continuous-flow system. The minimum interference from counter–ions and the attractive costs (around US$1.50/kg) compared to anion resins are added advantages for AA-based systems [iii].

Problems
Activated alumina also has some limitations. Due to the regeneration of activated alumina, a reduction of about 5–10% in material and 30–40% in capacity with an increased presence of aluminum (>0.2 mg/L) was reported. However, readjustment of pH to normal level may keep the aluminum residual within limits. Also, the pH-dependent defluoridation potential of alumina is worth mentioning. While it may be easy to adjust pH for maximum removal at a waterworks, it is necessary to depend on the actual pH of the raw water in domestic and small community treatments. So, for the design, capacity of available alumina has to be established through testing under authentic field conditions. Though high fluoride removal capacity of alumina (~4–15 mg/g) is reported in literature, field experiences demonstrate that it is often only about 1 mg/g. Thus, certain applications might have been limited by the difficulties of regeneration, the low capacity of less purified technical-grade products, and the relatively high price [iii].

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[15] Defluoridation of water using Activated Alumina Technology: Studies carried out at IIT Kanpur, UNICEF

[16] Tang Y, Guan X, Su T, Gao N, Wanj J. Fluoride adsorption onto activated alumina: Modeling the effects of pH and some competing ions. Colloids and Surfaces A: Physicochem. Eng. Aspects 337 (2009) 33–38

[17] Ayoob, S., Gupta, A. K. and Bhat, Venugopal T.'A Conceptual Overview on Sustainable Technologies for the Defluoridation of Drinking Water', Critical Reviews in Environmental Science and Technology, 38: 6, 401 — 470.

Case Studies

A cylindrical defluoridation unit was fabricated from MS sheet with the dimension of 0.5 m diameter and 1.5 m height. The unit was designed to operate in the upflow mode. 110 Kg of AA of grade G-87 (IPCL), having a particle size range of 0.3-0.9mm, was placed in the unit. This gave a bed depth around 55 cm. This unit was field tested at Makkur village, Unnao district U.P. A by-pass was provided to draw the water directly from the handpump for washing and bathing.
Advantages of this approach are:

- Lower cost for treatment, as only the volume of water required for cooking and drinking, which is less than 20% of total requirement, can be treated.
- Any chemical treatment is bound to generate waste, which needs safe disposal. As lesser volume is treated, there will be less sludge/waste production.
- However success of these approaches depend upon the treatment reliability and motivation of consumers to use only the treated water for cooking and drinking, (as the untreated water is also available) as well as on various other factors.

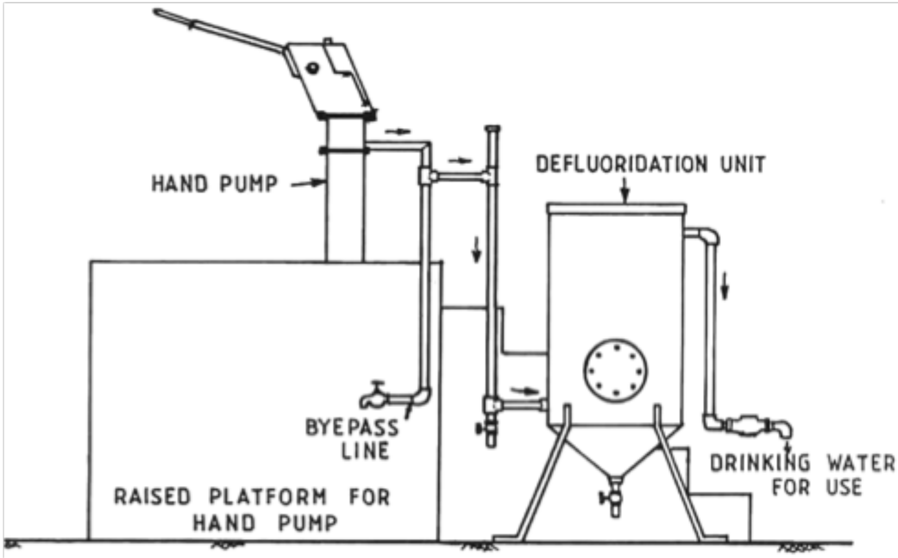

Figure 6: A hand-pump attached defluoridation unit

The unit was maintained by lIT Kanpur. Raw water fluoride concentration was in the range of 6-7 mg/L. Regeneration of exhausted activated alumina was carried out in situ i.e. within the column. This procedure required 8-10 hrs. Average yield of the safe water (<1.5 mg/L fluoride) per cycle was around 25,000 litres. Seventeen defluoridation cycles were completed in a span of 4 years. There was no major maintenance problem during this period. There was no complaint from the users either regarding the design or the palatability of treated water. Under experimental conditions used, FUC of indigenous AA grades ranged from 1500 mg/Kg AA and 2200 mg/Kg AA.

Scalability

Extensive literature is available on the application of Activated Alumina technology for defluoridation of drinking water in large treatment units.

Ease of Maintenance

Regeneration of exhausted AA and its reuse for multiple cycles is one of the main advantages of using AA for defluoridation. Different regenerants can be used including alum, HCI, H_2SO_4 and NaOH. The results clearly indicated that efficient regeneration could be achieved with a

combination of 1% NaOH and 0.4N H_2SO_4. Some AA grades showed less than 20% loss during 10 defluoridation cycles.
Regeneration of activated alumina generates spent alkali and acid having extreme pH values. Spent alkali regenerant would also have high fluoride concentration. Safe disposal of these regenerants is thus essential.
Different methods were tried for spent regenerant disposal. They included:

- The addition of $CaCl_2$ to spent alkali regenerant to precipitate fluoride and then mixing the supernatant with acid regenerant.
- Simple mixing of spent alkali/acid regenerants.
- Mixing alkali /acid regenerants and using certain additives like alum or lime to remove fluoride as well as to improve settling properties of the sludge.

Activated alumina in a handpump unit has to be periodically regenerated depending upon raw water characteristics, its fluoride concentration and amount of AA taken in the unit. There are two alternatives for the regeneration of activated alumina. One is "in situ" regeneration and the other option is by removing AA from the unit and transporting it to a regeneration centre. Regeneration of activated alumina leads to 6 to 8 bed volumes of wastewater. If the first option is chosen there should be a facility near the handpump for collecting the wastewater and its proper disposal. Hence the second option of centralized regeneration may be attractive only if many handpump units are in close proximity. However, such a facility would have to be institutionally operated.

Cost: Capital
Each of the defluoridation plants serves approximately 200-400 people. The average cost is Rs.35, 000/plant. Defluoridation filters are also used by people living in endemic areas. Each SS domestic filter cost Rs.1300 to Rs.1700 depending on the number of containers (1, 2 or 3) in the filter system, and the volume of the container (6, 10, 18 or 27 liter). In the filter system, the unit which is sealed with AA is exchangeable for a new one at a nominal charge. Flow is 10 litres / hour. The main component of the unit is PVC basket containing 3 Kg of activated alumina giving a bed depth of 17 cm [18].

2.6 Rain Water Harvesting

Introduction
Only 40% of total precipitation can be extracted from surface water (rivers, streams and lakes) and groundwater (wells and boreholes). Hence rainwater harvesting can help collect more freshwater. There are three main techniques used:

- Storage of rainwater on surface for future use.
- Recharge to groundwater.
- Directly collected rainwater can be stored for direct use or can be recharged into the groundwater.

The objective of water harvesting in India differs between urban and rural areas. In urban areas, emphasis is put on increasing groundwater recharge and managing storm water. On the other hand, in rural areas securing water is more crucial. There the aim is to provide water for drinking and farming, especially for life-saving irrigation, and to increase groundwater recharge. *About 85% of*

[18] Eswar P. Devaraj C. Water defluoridation: Field studies in India. INDIAN JOURNAL OF DENTAL ADVANCEMENTS 3(2), April-June, 2011, p-526-533.

rural and 55% of urban India's drinking water needs are met from ground water but indiscriminate pumping of water from deep aquifers is leading to rapid depletion of ground water resources in the country. It is in this context that the roof top rain water harvesting in India assumes an importance for artificially augmenting the recharge. Except for the initial capital outlay and creating additional surface installations like settling tanks for silt removal and chlorination / UV radiation treatment plants to meeting the acceptable standards of potable water, the scheme of roof-top rain water harvesting for augmenting ground water storage is economically feasible, eco-friendly and beneficial.

Advantages of rainwater harvesting

- Relatively cheap materials can be used for construction of containers and collecting surfaces
- Construction methods are relatively straightforward
- Low maintenance costs and requirements
- Collected rainwater can be consumed without treatment providing a clean collecting surface has been used
- Provides a supply of safe water close to homes, schools or clinics: reduces time women and children spend collecting water, reduces strain or injuries from carrying heavy containers

Disadvantages of rainwater harvesting

- Supplies can be contaminated by bird/animal droppings on catchment surfaces and guttering structures unless they are cleaned/flushed before use
- Poorly constructed water jars/containers can suffer from algal growth and invasion by insects, lizards and rodents. They can act as a breeding ground for disease vectors if they are not properly maintained.

<u>India: Rainfall and Evaporation Data</u>

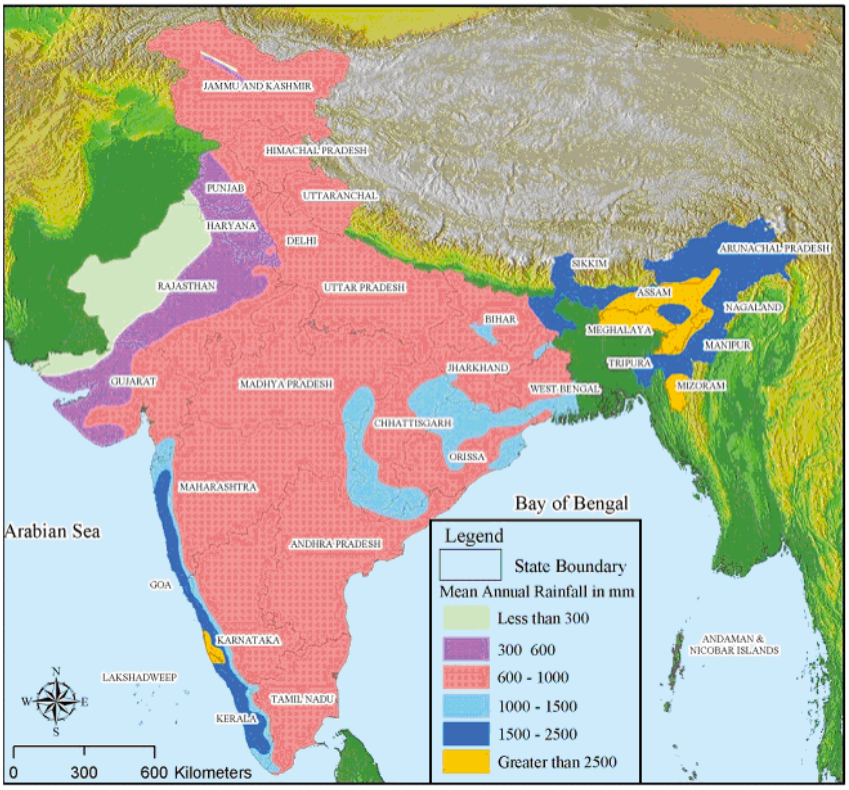

Figure 7: Mean Annual Rainfall Data - India

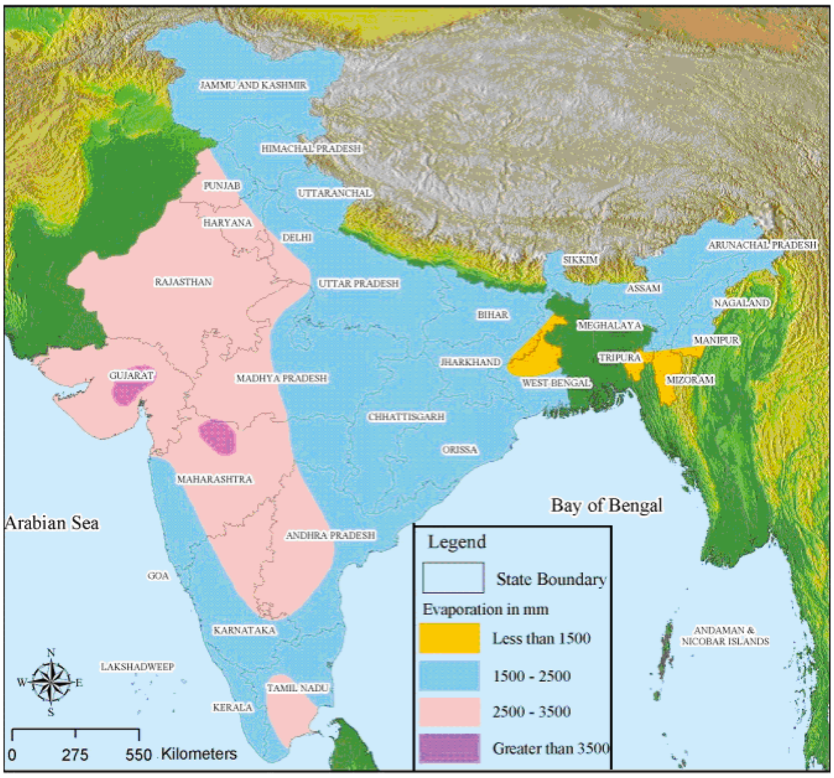

Figure 8: Evaporation Data - India

<u>Components</u>

Roof catchments

Rainwater can be collected from most forms of roof. Tiled roofs, or roofs sheeted with corrugated mild steel etc are preferable, since they are the easiest to use and give the cleanest water. Thatched or palm leafed surfaces are also feasible; although they are difficult to clean and can often taint the run-off. Asbestos sheeting or lead-painted surfaces should be avoided. The rainwater is collected in guttering placed around the eaves of the building. Low cost guttering can be made up from 22 gauge galvanised mild steel sheeting, bent to form a 'V' and suspended by galvanised wire stitched through the thatch or sheeting, as shown in the following diagram:

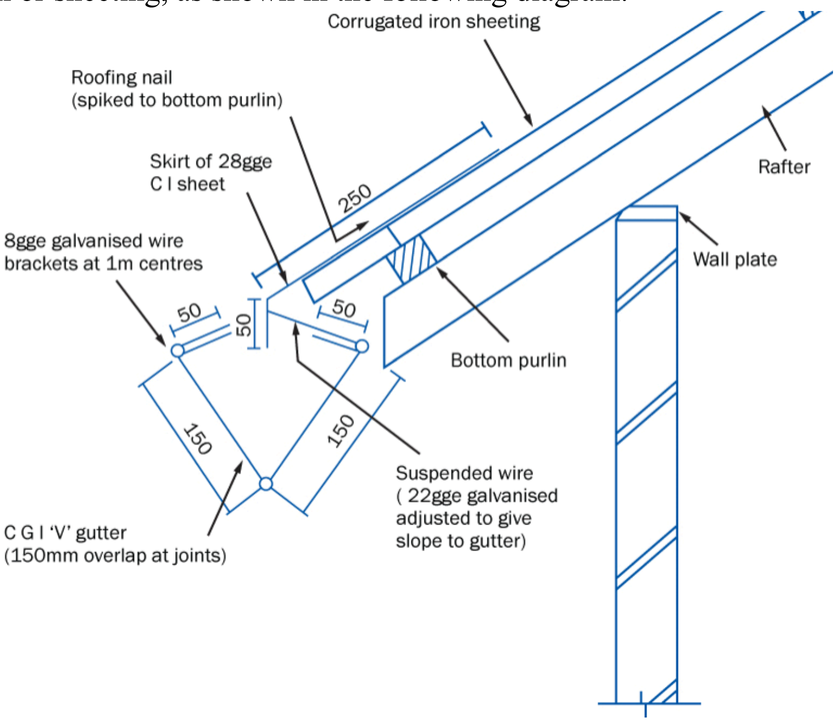

Figure 9: Section of Typical Roof Guttering

First foul flush

The guttering drains to a down-pipe which discharges into a storage tank. The down-pipe should be made to swivel so that the collection of the first run-off can be run to waste (the first foul flush), thus preventing accumulated bird droppings, leaves, twigs and other vegetable matter, as well as dust and debris, from entering the storage tank. Sometimes a collecting box with a mesh strainer (and sometimes with additional filter media) is used to prevent the ingress of potential pollutants.

There are four typical methods of separating the first flush;

- Manual
- Fixed volume
- Fixed mass
- Flow rate

The **manual method** is the simplest and widely recommended, however it relies on the user both being present and willing to go out into the rain to operate the device, and therefore its usefulness is limited. The **fixed volume method**, which relies on the water simply filling a chamber of a set size (usually a length of downpipe) until it overflows, is the "automatic" method usually applied in low cost systems.

Storage

The provision of the storage tank is the most costly element of a rainwater harvesting project: typically about 90% of the total cost. Storage can range from small containers made for other purposes, for example oil drums, food cans etc, but used as domestic storage, up to large tanks of 150 cubic metres or more at ground level, or sometimes beneath it. These tanks are made of concrete or ferrocement and are used as storage for schools, clinics or other institutions with large areas of roof. Large cement tanks can be made simply. However the option of re-filling underground aquifers should also be considered.

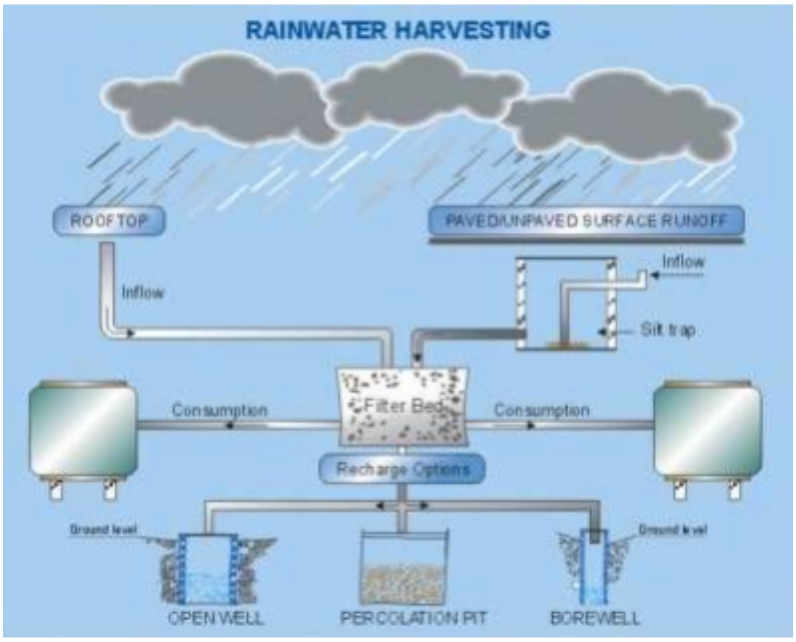

Figure 10: Schematic of Rainwater Harvesting and Storage System Options

Where and how it works

The **catchment** of a water harvesting system is the surface which directly receives the rainfall and provides water to the system. A **conveyance system** usually consists of gutters or pipes that deliver rainwater falling on the rooftop to cisterns or other storage vessels. These should be chemically inert materials. The water ultimately is stored in a **storage tank or cistern**, which should also be constructed of an inert material: common options are listed below.

Materials

In addition to the materials listed in table x below, plastic or ferro-cement tanks of similar capacity are another material option. A disadvantage posed by plastic tanks is that they have a low proportion of their cost in the form of local labour, which may be an important feature of subsidised RWH programs in rural areas. Ferro-cement tanks, Gl sheet tanks and properly lined brick masonry tanks are low-cost storage options. However ferro-cement and brick masonry tanks are not as water-tight. GI sheets can rust and impart an undesirable taste to the stored water. The stored water can be stored cleanly for months or years in suitable RW tanks. Observations in India showed good quality even after 180 days of storage, and in South Africa even after 2 years. However, such long storage time will require good maintenance of RWH systems such as regular cleaning of RW tanks, roof surfaces and water in storage kept in dark and sealed conditions. Collection gutters, down pipes and filters are often poorly made or not maintained, and therefore constitute the main form of system failure.

Type	Runoff Coefficient	Remarks
Galvanised Iron Sheets	>0.9	• Excellent quality water. Surface is smooth and high temperatures help to sterilise bacteria
Tile (glazed)	0.6 – 0.9	• Good quality water from glazed tiles. • Unglazed tile can harbour mould • Contamination can exist in tile joints
Asbestos Sheets	0.8 – 0.9	• New sheets give good quality water • No evidence of carcinogenic effects by ingestion • Slightly porous so reduced run-off coefficient and older roofs harbour moulds and even moss
Organic (Thatch, Palm)	0.2	• Poor quality water (>200 FC/100 ml) • Little first-flush effect • High turbidity due to dissolved organic material which cannot easily be filtered or settled out

Table 7: Material Types

Aquifer Recharge (AR)

AR by rainwater will also help to qualitatively improve contaminated groundwater aquifers by reducing the concentration of pollutants by dilution. Widespread adoption of AR will alleviate the severely degraded groundwater aquifers in many Indian towns and cities. Rainwater may be recharged into the groundwater aquifers through any suitable structures like dugwells, borewells, recharge trenches and recharge pits. Various recharge structures are possible - some which promote the percolation of water through soil strata at shallower depth (e.g. recharge trenches, permeable pavements). Others conduct water to greater depths from where it joins the groundwater (e.g. recharge wells). At many locations, existing structures like wells, pits and tanks can be modified as recharge structures, eliminating the need to construct any structures afresh. This report believes aquifer recharge is a very promising rainwater harvesting option for rural India.

Below are some of the commonly used recharging methods:

Recharging of Dugwells and abandoned Tubewells
In alluvial and hard rock areas, there are thousands of wells which have either gone dry or hose water levels have declined considerably. These can be recharged directly with rooftop run-off.

Recharge pits
A recharge pit is typically 1.5m to 3m wide and 2m to 3m deep. The excavated pit is lined with a brick/stone wall with openings (weep-holes) at regular intervals. The top area of the pit can be covered with a perforated cover. Design procedure is the same as that of a settlement tank.

<u>Maintenance</u>
Rainwater harvesting systems don't require significant professional/technical expertise or significant supervision to operate. Major concerns are the prevention of contamination of the tank during construction and while it is being replenished during a rainfall. The main sources of external contamination are pollution from the air, bird and animal droppings, and insects. Bacterial contamination may be minimised by keeping roof surfaces and drains clean but cannot be completely eliminated. If the water is to be used for drinking purposes, filtration and chlorination or disinfection by other means (e.g., boiling) is necessary. The following maintenance guidelines should be considered in the operation of rainwater harvesting systems:

- A procedure for eliminating the "first foul flush" after a long dry spell deserves particular attention. Generally, water captured during the first 10 minutes of rainfall during an event of average intensity is unfit for drinking purposes. The quantity of water lost by diverting this runoff is usually about 14l/m2x of catchment area.
- The storage tank should be checked and cleaned periodically. All tanks need cleaning; their designs should allow for this. Cleaning procedures consist of thorough scrubbing of 30 the inner walls and floors. Use of a chlorine solution is recommended for cleaning, followed by thorough rinsing.
- Care should be taken to keep rainfall collection surfaces covered, to reduce the likelihood of frogs, lizards, mosquitoes, and other pests using the cistern as a breeding ground.
- Gutters and downpipes need to be periodically inspected and cleaned carefully. Periodic maintenance must also be carried out on any pumps used to lift water to selected areas in the house or building. In existing systems, more often than not, maintenance is done only when equipment breaks down.
- Households must establish a maintenance routine that will be carried out by family members. As has been noted, in some cases the rainwater is treated with chlorine tablets. However, in most places it is used without treatment. In such cases, residents are advised to boil the water before drinking. Where cistern users do not treat their water, the quality of the water may be assured through the installation of commercially available in-line charcoal filters or other water treatment devices.

Assumptions for effectiveness:
One of the most important underlying values in rainwater harvesting is that it is a benign technology (Bachelor et al. 2002) and cannot create undesirable consequences. Water harvesting initiatives are driven by firm beliefs and assumptions, some of which are:

1. That there is a huge amount of monsoon flow, which remains un-captured and eventually ends up in the natural sinks, e.g. oceans;
2. That local water needs are too small and as such exogenous water is not needed;
3. That local water harvesting systems are always small and, therefore, are cost-effective;
4. Since the economic, social and environmental values of water are very high in regions hit by water shortages, water harvesting interventions are viable, supported by the assumption that cost- effective alternatives that can bring in the same amount of water, do not exist;
5. Incremental structures lead to incremental benefits; and 6) being small with low water storage and diversion capacities, they do not pose negative consequences for downstream uses.

Case Studies

Case Study 1: Kishangarh – City use and aquifer regeneration

Unit configuration
The water table in Kishangarh is found to be at 5.5m, which goes down to approximately 7.0 m during dry season. Given that the building has 1 50 sq. m. of roof top area, a recharge trenches of 4 m long, 3 m wide and 3 m deep called "collection and filtration pit" is constructed in the same campus of dwelling unit (Figure x). The trench is filled with boulders at the bottom followed by pebbles and sand at the top This infiltration pit is directly connected to the existing bore well. The roof-top rain water is channelled through 10 cm diameter pipe to the existing bore hole of the hand pump which is used here to act as the recharge shaft that ends into the aquifer under gravity flow conditions through collection and filtration pit (to make it silt free) and recharge pit.

Results
During monsoon period of June to August, 2001, the scheme was put to use and it was observed that the hand pump which used to remain dry even after the monsoon period started flowing in the month of September, indicating a rise in the water level of the aquifer. This option of roof-top rain water harvesting is found to be the most appropriate for augmenting local groundwater level in the dwelling unit of congested Kishangarh residential area in East Delhi as the recharge in the area is considerably reduced due to increased urban activities and not much of land is available for implementing any other artificial recharge measure. It requires only one time large investment and subsequently with proper maintenance, the entire system can run indefinitely. Such local initiatives have reduced the dependence on imported water.

Advantages and Disadvantages
The following benefits are accrued from the scheme
1. Limited additional regular water supply in the area during dry season.
2. Land surface, installations and working entirely unaffected.
3. The basic infrastructure is expected to last indefinitely and is suitable for any further expansion.

4. However, the only drawback or short coming is that it attracts large initial capital expenditure and requires additional surface installations for chlorination / UV radiation treatment plants for making the collected water acceptable standard potable water. In addition, collection and filtration pit also requires periodical cleaning after rainy season.

Conclusions and Recommendations

Based on the available hydrogeological conditions and data, the roof-top rain water conservation through injection technique is found to be most suitable in the present site of investigation at Kishangarh in East Delhi where land availability was limited due to very high population density and the aquifer was deep and overlain by impermeable strata.

Case Study 2: Construction of household rainwater harvesting jars in Uganda

WaterAid has been working to improve household water supplies in a Ugandan village where 3,000 people lack access to safe water. Rainwater harvesting jars are made from locally available materials and have a capacity of 1,500 litres which is equivalent to 75 jerry-cans of water. The objective has been to help the community construct on-site water supplies, close to the home, thus removing the need for the old or infirm to travel long distances across difficult terrain to collect water. The jars have a long design life and once constructed can provide a stable water source for many years.

Construction methodology:

1. Fifty bricks are used to assemble a stable platform upon which the jar is constructed.
2. A one metre long copper pipe is shaped and laid in the brick base. This will channel water from the jar to the tap fitting.
3. A reusable wooden mould is assembled from 12 component pieces on top of the brick base.
4. The outside of the mould is smeared with mud for approximately three hours.
5. It is left to stand for three days after which it is plastered with normal cement.
6. The jar is left to dry for four days, giving time for the cement to set. After four days the mould is removed by extracting individual pieces from the mouth of the jar. The layer of mud inside the jar is also removed.
7. The inside of the jar is then sealed using water proof cement.
8. Community members provide guttering for their roofs and a plastic basin which is perforated to act as a filter at the top of the jar. Some jars have lockable tap chambers attached to their base to prevent theft of water.

Materials required:

- Locally made bricks for base (50)
- Three bags of sieved sand
- One bag of normal cement
- One kilogram of waterproof cement
- A wooden mould that can be reused to make a number of jars
- One metre copper pipe
- One brass tap

All jars are made in situ as they are fragile to transport. Each jar costs around £35 to make. This cost can be shared between five households.

References: Rainwater Harvesting

- “Design & policy issues on rainwater harvesting in India” Punam Kumari 2009, Dissertation submitted to - National Law School of India University Bangalore
- “Water Harvesting Induced by Reduction of Both Evaporation and Deep Percolation of Water under Some Growing Crops” I. S. Al-Salamah and I. N. Nassar
- E-WAter Official Publication of the European Water Association (EWA) © EWA 2008 ISSN 1994-8549
- Water Aid, Rain water harvesting
- “Rainwater Harvesting in the Water-scarce Regions of India: Potential and Pitfalls”, M. Dinesh Kumar1, Ankit Patel1 and O.P. Singh2, 1 IWMI-TATA Water Policy Program, Hyderabad, India, 2 Benaras Hindu University, Varenasi, India