Microbial counts and pesticide concentrations in drinking water after alum flocculation of channel feed water at the household level, in Vinh Long Province, Vietnam

Tim Wrigley

ABSTRACT

Low technology water supply, treatment and sanitation techniques were reviewed in a Vietnamese village in the Mekong River Delta as part of an AusAID Project to reduce poverty and to improve the overall living standards and health in the Cuu Long (Mekong) delta for 500,000 rural poor.

It was found that dosing of canal water in 200-l ceramic jars with alum, PAC or PAC followed by hypochlorite provides a high level of treatment for drinking water at the household level in a rural village setting in the Mekong River delta.

Seventy per cent (7 in total) of the 24 samples collected showed that *Escherichia coli* levels per 100 ml in the jars after treatment showed a 'no risk' profile (0 *E. coli* 100 ml^{-1}) i.e. the water would be considered to be of very good quality for drinking according to World Health Organization Guidelines for Rural Drinking Water Supply. This included the eight samples that were dosed with hypochlorite. The remaining 30% of samples (seven in total) ranged from 14 to 47 *E. coli* 100 ml^{-1} which is considered an intermediate risk (10–100 *E. coli* 100 ml^{-1}) according to WHO guidelines. All control water samples (eight in total) were high or very high risk ($>$100 *E. coli* 100 ml^{-1}).

Pesticide concentrations generally were low and met Vietnamese drinking water quality criteria.

Key words | alum and PAC with hypochlorite flocculation, coliform, *E. coli*, household treatment, pesticides, WHO rural drinking water guidelines

Tim Wrigley
Geographical Sciences and Planning,
University of Queensland,
Brisbane,
Australia
E-mail: *timj_wrigley@yahoo.com.au*

INTRODUCTION

While the extent to which even safe water becomes faecally contaminated during collection, transport, storage and drawing in the home is well known (Wright *et al.* 2003), only recently have low-cost health interventions been promoted to improve and preserve water quality at the household level (Mintz *et al.* 2001). Based on a comprehensive review of these interventions, the World Health Organization (WHO) concluded that there was now 'conclusive evidence that simple, acceptable, low-cost interventions at the household and community level are capable of dramatically improving the microbial quality of household stored water and reducing the attendant risks of diarrhoeal disease and death' (Sobsey 2002).

An analysis of 21 controlled field trials over the last 20 years dealing specifically with interventions designed to enhance the microbiological quality of drinking water at the household level showed a median reduction in endemic diarrhoeal disease of 42% compared with the control groups (Clasen 2003).

The result was fairly consistent regardless of the nature of the intervention. Eight studies using free chlorine

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produced a median reduction of 46% (Kirchhoff *et al.* 1985; Sircar *et al.* 1986; Mahfouz *et al.* 1995; Handzel 1998; Semenza *et al.* 1998; Quick *et al.* 1999, 2002; Sobsey *et al.* 2003); four studies examining filtration had a median reduction of 40% (Payment *et al.* 1991; Hellard *et al.* 2001; Clasen *et al.* 2003; Colwell *et al.* 2003); three studies employing flocculation or a combination of flocculation and disinfection showed a median reduction of 38% (Kahn *et al.* 1984; Luby *et al.* 2001; Reller *et al.* 2003), and four studies of heat or solar radiation produced a median reduction of 35% (Conroy *et al.* 1996, 1999, 2001; Iijima *et al.* 2001). Only 2 of the 21 intervention studies showed no statistically significant reduction when compared with controls (Kirchhoff *et al.* 1985; Hellard *et al.* 2001). A number of authors, including Oo *et al.* (1993), Wrigley (2002) and Crump *et al.* (2004), have reviewed the use of alum as a disinfectant agent at the household level. Experiments using well and pond water treated with a range of doses of alum and inoculated with *Escherichia coli* or *Vibrio cholerae* at fixed concentrations show that alum doses of 500 g ml^{-1} reduced 8-h survival of both organisms (Khan *et al.* 1984; Oo *et al.* (1993) found traditional alum flocculation substantially reduced both *E. coli* and total coliform numbers from shallow well water.

Wrigley (2002) investigated the use of alum as a flocculant at a household level for water quality improvement for waters drawn from the Mekong River. Coliform numbers were reduced by three orders of magnitude or 99% after one hour and to non-detectable numbers after 6 hours of stirring the water with alum.

This study is a continuation of the earlier work undertaken by Wrigley (2002) to establish whether using alum as a flocculent was a cost effective form of water treatment for householders of the Mekong River basin, as well as being culturally acceptable and technologically appropriate.

The microbial drinking water quality of a household within a Vietnamese community in the Mekong River delta, Vietnam, was investigated. If the study results established that the present method of dosing canal or river water with alum at the household level was providing acceptable drinking water quality, this technique could be considered as another option to assist the very poor in rural situations.

MATERIALS AND METHODS

Testing was carried out at the Chanh Hoi Commune, Vinh Long Province. This village was located next to a canal from which much of its domestic water supply was drawn. Domestic water use was also supplemented with rainwater gathered during the wet season and stored in jars. The 200-l jars were made of either clay or concrete.

The following procedure included three treatments with a control and was undertaken in paired 200 litre jars.

- Treatment 1 - Rock alum ($Al\ NH_4\ SO_4$) was used for dosing
- Treatment 2 - A commercial package of poly aluminium chloride (PAC) (~2 g) was used for dosing
- Treatment 3 - A commercial package of poly aluminium chloride (~2 g) and hypochlorite (~2 g) was used for dosing

The jars were emptied the previous day as per normal practice to remove any sediment. The rock alum was held for approximately 2 minutes as pumped canal water flowed over the householder's hand into the jar. The poly aluminium chloride powder (~2 g) was dissolved in a 5-l bucket before being poured into the 200 l jar. The poly aluminium chloride (~2 g) and hypochlorite (~2 g) were dissolved in a 5-l bucket before being poured into the 200 l jar. The control jars were filled with pumped canal water.

SAMPLING PROCEDURES AND TESTING

Two canal water samples were collected in sterilised glass 250 ml bottles when the jars were filled. Water samples were collected from all eight jars at the following times post dosing treatment: 1 h, 2 h, 6 h and 24 h. Sterile bottles (250 ml) were filled using sterile glass pipettes.

All bottles were stored on ice and transported to the Pasteur Institute of Ho Chi Minh City the same day so testing was completed within 24 hours of collection.

Table 1 shows the parameters measured and analysed on each collected sample either at the Pasteur Institute or the Vietnamese National Water Laboratory in Ho Chi Minh City.

Table 1 | Water testing parameters

Microbiological	Physical	Chemical
Total coliform	Turbidity	Pesticides
Faecal coliform	pH	Aluminium
E. coli	Salinity	
Streptococci		
Vibrio cholerae		

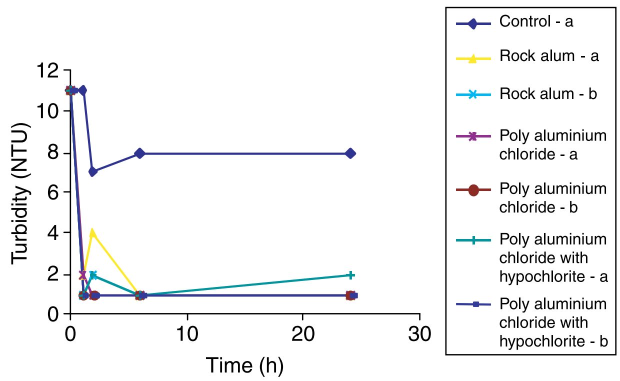

Figure 1 | Changes in turbidity after alum dosing over a 24 hour period.

DESCRIPTION OF DOSING MATERIALS

In the village, water usage for each household was in the order of a 200 l jar per day.

Rock alum

Rock alum (Al NH_4 SO_4) is mined in the Mekong Delta. It is readily available in the local markets and can be purchased for approximately 3,000 dong per kg (14,000 dong to US$1). A block the size of a baseball (200 g) would last for nearly 2 weeks.

Poly aluminium chloride with hypochlorite

Poly aluminium chloride (PAC) is a high molecular weight inorganic compound. Better coagulation is obtained with PAC when compared with alum in medium and high turbidity waters with floc formation occurring very rapidly (Malhotra 1994). Hypochlorite when added to the poly aluminium chloride provides a strong disinfection element. The reduction in suspended material in the water column would enhance the effectiveness of the hypochlorite.

PAC is readily available on the market and comes with a sachet of hypochlorite. The cost for a packet of 10 sachets was 3,000 dong. One sachet of PAC was added to a 200 l jar.

RESULTS

Changes in turbidity

Turbidity of water from the canal was relatively low (10–12 NTU) (Figure 1). These levels rapidly decreased after alum dosing to less than 5 NTU after 2 hours. There was no decrease in control turbidity during the 24-hour period.

After 1 hour, turbidity levels in the jars with crushed alum and crushed alum and chloride were 1–2 NTU. This water was essentially clear. Jars using rock alum had slightly higher turbidity levels at 1 and 2 hours after dosing of 4–7 NTU. After 6 hours, all treated jars had turbidity levels between 1 and 2 NTU.

Changes in total coliform numbers

The reduction in total coliform numbers was high with a 90–95% reduction within the first hour (Figure 2). Low numbers remained over the 24 hours in all treated jars. The jars treated with poly aluminium chloride with hypochlorite all recorded zero bacterial numbers except for one jar on one single occasion.

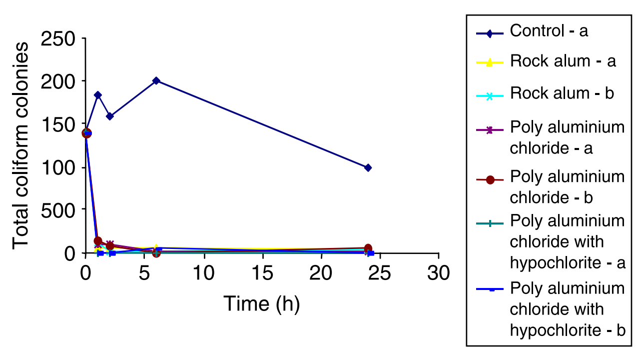

Figure 2 | Changes in total coliform numbers after alum dosing over a 24 hour period.

Changes in faecal coliform numbers

The level of removal of faecal coliforms was high, with a 95% removal efficiency for the bulk of the samples tested. The jars treated with poly aluminium chloride with hypochlorite all recorded zero bacterial numbers except for one jar on one single occasion (Figure 3).

Changes in *E. coli* numbers

E. coli numbers in this experiment were reduced by 95% throughout the sampling period. There were no *E. coli* recorded in the jars with PAC and hypochlorite dosing (Figure 4).

Changes in streptococci and *Vibrio cholerae* numbers

Streptococci numbers were low (<10) after dosing. No *Vibrio cholerae* were found in either the raw or treated water samples

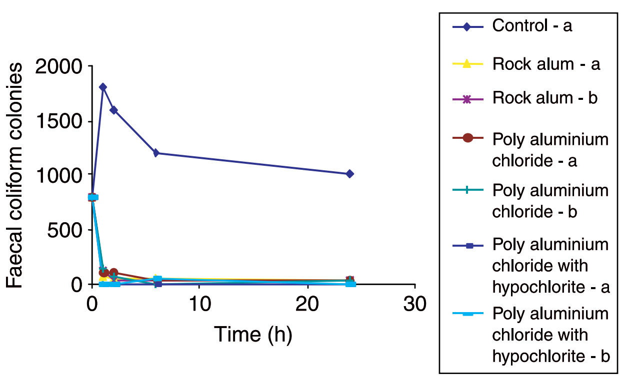

Figure 3 | Changes in faecal coliform numbers after alum dosing over a 24 hour period.

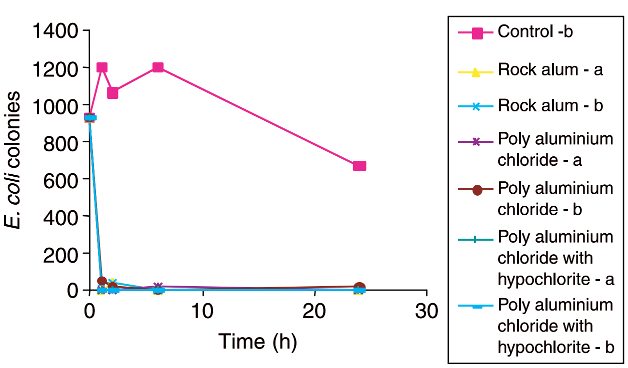

Figure 4 | Changes in *E. coli* numbers after alum dosing over a 24 hour period.

Changes in pH values

pH values remained relatively unchanged after alum dosing. There was an initial drop of up to 0.6 pH units to 6.4 after 1–2 hours (see Figure 5). The pH of the jar water then rose by between 0.3 and 0.5 units, then stabilised at slightly lower than the original pH values of the raw water.

Changes in aluminium concentrations

Aluminium concentrations in the jars were higher then the control canal water samples. The Vietnamese drinking water criteria of $0.2\,mg\,l^{-1}$ was exceeded at the 2 h aluminium concentrations for most treatments. These concentrations then decreased to the drinking water criteria within 6 hours except for the jars dosed with rock alum (see Figure 6).

Though these concentrations were above the drinking water criteria, there appears be no or little risk of chronic health effects by ingestion of treated drinking water.

Changes in pesticide concentrations

There is a concern that, particularly in the dry season, pesticide levels may high in drinking water supplies. Pesticide concentrations measured in jars before and after dosing are listed in Table 2. The figures in bold represent concentrations above Vietnamese drinking water criteria.

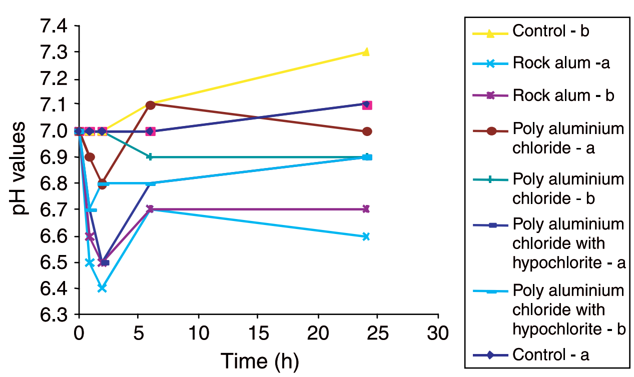

Figure 5 | Changes in pH after alum dosing over a 24 hour period.

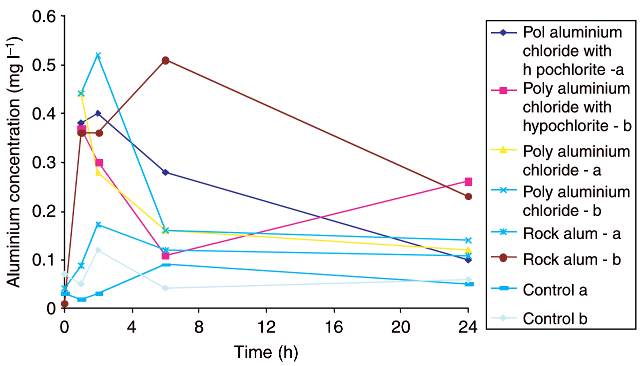

Figure 6 | Changes in aluminium concentrations (mg l^{-1}) after alum dosing over a 24 hour period.

DISCUSSION

Turbidity

The turbidity of the water of the canal was relatively low (15 NTU). By contrast Wrigley (2002) recorded turbidity levels in the Tonle Sap River, Cambodia, of 135 NTU before alum dosing. The canal was connected to the river system, though the exchange with the river was restricted by a road and small outlet pipe. Daily tidal pulses provided some exchange to the canal.

Sampling occurred in April, at the end of the dry season, so water in the canal and associated river system had probably lost much of its suspended wet season load.

Bacterial results

E. coli numbers are used by the World Health Organization to determine the quality of drinking water (Table 3). A summary of microbiological water quality within the village after dosing is presented in Table 4.

There was a very low risk in terms of microbial water quality and health based on these results when compared with the World Health Organization (WHO) Water Quality Guidelines for Rural Drinking Water Supplies (1997). The hypochlorite dosed jars showed a 'no risk' profile. Rock alum had a 50–75% no risk profile, while PAC was lower with a 25–75% no risk profile. The remaining profiles for both rock and PAC were 'intermediate risks' according to the WHO Guidelines. All control values were high or very high risks according to these guidelines.

Crump *et al.* (2004) also evaluated alum and hypochlorite at the household level in western Kenya in water from 30 sources. A combined flocculant-disinfectant reduced *E. coli* concentrations to <1 CFU 100 ml^{-1} for 29 (97%) of the sources and reduced turbidity to <5 NTU for

Table 2 | Changes in pesticide concentrations (μg l^{-1}) in jars after treatment over 24 hours (LOR, limit of recording)

Time (h)	Pesticide	Drinking water criteria μg l^{-1}	Control	Rock alum	Poly aluminium chloride	Poly aluminium chloride with hypochlorite
0	Hexachlorobenzene	1	0.11–0.21			
	Heptachlor	0.03	< LOR			
	Aldrin/dieldrin	0.03	< LOR			
2	Hexachlorobenzene	1	0.05–0.13	0.25	**3.03**	0.40
	Heptachlor	0.03	< LOR	< LOR	**0.03**	< LOR
	Aldrin/dieldrin	0.03	< LOR	< LOR	**0.51**	< LOR
24	Hexachlorobenzene	1	0.05– 0.13	0.11	0.13	0.15
	Heptachlor	0.03	< LOR	< LOR	< LOR	< LOR
	Aldrin/dieldrin	0.03	< LOR	< LOR	< LOR	0.06

Table 3 | World Health Organization Water Quality Guidelines for Rural Drinking Water Supplies (1997)

E. coli count per 100 ml	Classification
0	Conforms to WHO guidelines
1–10	Low risk
10–100	Intermediate risk
100–1,000	High risk
>1,000	Very high risk

26 (87%) of the sources. By contrast, for water from 30 sources, sodium hypochlorite treatment reduced *E. coli* concentrations to <1 CFU 100 ml^{-1} for 25 (83%) sources and turbidity to <5 NTU for 5 (17%) sources.

The conclusions of Crump *et al.* (2004) are similar to those of this paper whereby the novel flocculant-disinfectant product may be acceptable to consumers and is likely to be effective in reducing diarrhoeal disease in settings where source water is highly turbid.

Oo *et al.* (1993) also found in Myanmar that traditional alum flocculation without disinfectant mitigates turbidity but does not reliably reduce *E. coli* concentrations to <1 CFU 100 ml^{-1}. Nonetheless, traditional alum flocculation does substantially reduce both *E. coli* and total coliform numbers. Previous evaluation of alum for decontaminating shallow well water also showed substantial reductions in faecal coliform numbers.

Alum treatment of household water has been demonstrated to reduce secondary transmission within households during a cholera epidemic in Bangladesh (Khan *et al.* 1984).

These results across a wide range of countries at the household level clearly demonstrate the value of alum as a residual bactericide for stored water. Whether it is the flocculation of the suspended material within the water column or some bactericidal property of the alum or a combination of the two that is responsible for the reduction in bacterial numbers is still to be determined.

It is evident that alum coupled with hypochlorite can deliver high quality drinking water at the household level in a cost effective, culturally appropriate and technically suitable manner for a large number of rural people.

Review of health implications of trace aluminium in drinking waters

The WHO indicates that there is confusion and misinformation surround the health risks associated with aluminium in drinking water. The link between neurological effects and aluminium in drinking water is particularly elusive because of the high intake of aluminium from food (average adult intake 5.0 mg per day) which obscures the effects of aluminium ingested in water from additives such as alum. However, after a recent, detailed study, the WHO concluded that:

> 'Aluminium has not been demonstrated to pose a health risk to healthy, non-occupationally exposed humans.

Table 4 | Percentage of samples for each treatment which meet WHO guidelines for *E. coli* per 100 ml from rural drinking water supplies (number of samples recorded in brackets)

Treatment	Rock alum (a)	Rock alum (b)	PAC (a)	PAC (b)	PAC with hypochlorite (a)	PAC with hypochlorite (b)	Control
No risk % (0 *E. coli* 100 ml^{-1})	75 (3)	50 (2)	75 (3)	25 (1)	100 (4)	100 (4)	
Low risk % (1–10 *E. coli* 100 ml^{-1})	0	0	0	0	0	0	
Intermediate risk % (10–100 *E. coli* 100 ml^{-1})	25 (1)	50 (2)	25 (1)	75 (3)	0	0	
High risk or very high risk % (>100 *E. coli* 100 ml^{-1})	0	0	0	0	0	0	100 (8)

There is no evidence to support a primary causative role of aluminium in Alzheimer's disease, and … there is insufficient health-based evidence to justify revisions to existing WHO guidelines … [and] inadequate scientific basis for setting a health-based standard for aluminium in drinking water' (WHO 1997).

Pesticides

The levels of organochlorides measured generally meet the Vietnamese drinking water criteria. In one jar, these concentrations increased though reasons for these increases are unclear (Table 2).

CONCLUSIONS

Alum and hypochlorite dosing of canal waters at a household level in the Mekong River delta significantly reduced the numbers of potential pathogenic bacteria. Pesticide residual levels were low in canal waters.

Some residual bacterial levels represented an 'intermediate risk' according to the WHO Water Quality Guidelines for Rural Drinking Water Supplies (1997) when waters were only dosed with alum or PAC.

The cost of alum dosing at the household level is low and is widely adopted in villages across the Mekong River delta and further upstream in Cambodia. Boiling of these waters is also common practice after alum dosing and provides another level of disinfection.

PAC dosing with hypochlorite, which also delivers a high quality disinfected water, is used by more affluent members of the community such as shop keepers.

This information about the delivery of good quality drinking water provided by these simple but effective means of disinfection should be more widely disseminated to other riparian countries of the Mekong River.

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