Development of Low-cost Technologies for Treatment of Contaminated Water in Flood Affected Areas

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Abstract

Flood is a yearly event in Bangladesh and people in the flood-affected areas suffer from waterborne diseases due to non-availability of potable water. During floods, people are advised to treat water through boiling, alum dosing and chlorination. However, there are no clear guidelines for proper application of these processes. For the development of suitable water treatment technologies, five simple technologies were investigated. These were alum coagulation, chlorination, alum coagulation-chlorination, boiling and storing. The quality of locally available chlorine tablets and bleaching powders were also evaluated. Water samples were collected from street taps, hand-pump tubewells, stagnant floodwater and rivers during the 1998 flood. The experimental results showed that: (i) heating water just upto the boiling point was sufficient to destroy pathogens, (ii) chlorination was quite effective in killing pathogens at a chlorine dose of 0.5 to1.0 mg/L with 30 minutes contact time, (iii) alum dosing of 200 mg/L effectively reduced the turbidity of floodwater but it could not make the water bacteria free even at much higher doses, (iv) colored and turbid floodwater could be treated with simultaneous application of chlorination and alum coagulation. The required alum dose was 200 mg/L and the chlorine dose was 0.5 mg/L with 30 minutes settling time/contact time, and (v) the quality of the available chlorine disinfectant varied widely and the local chlorine tablets were better than foreign tablets. Based on these findings, recommendations were made for practical applications of the developed technologies.

INTRODUCTION

Flooding and consequent human sufferings and loss of property is a common phenomenon in Bangladesh. Although flooding is a yearly phenomenon in Bangladesh, in some years, it becomes devastating causing widespread havoc and human misery. The 1998 flood brought such widespread havoc in much of Bangladesh. Human misery caused by flooding that year had probably surpassed all previous records because of its prolonged duration, reaching about two months for some parts of Bangladesh. Lack of potable water and sanitation facilities is responsible for the greatest human miseries in the flood-affected areas. In fact, most of the deaths during and immediately after floods have been linked to water borne diseases such as diarrhea, cholera, typhoid, etc.

In most areas of Dhaka, water is supplied through an age-old distribution system of the Dhaka Water Supply and Sewerage Authority (DWASA). During flooding, contaminated water from overflowing sewers and other sources enter into the water supply lines through numerous leaks in the distribution system. In addition, water in the underground reservoirs at many households becomes contaminated with overflowing polluted water. Many tubewells also become inoperable. Absence of proper facilities for excreta disposal, and disposal of solid and liquid wastes make the water quality situation even worse.

During flooding, people in the flood-affected regions were advised not to use DWASA supplied water or water from any other source (e.g., tubewell water and pond-water) without treatment. Common water treatment methods used by people in flood affected areas include (a) use of water disinfectants available in tablet forms in the market, and (b) boiling of water.

Effectiveness of the disinfectant tablets and their recommended doses has been widely questioned during flood episodes. Wide ranges of such tablets are available in the market and there is an urgent need to evaluate the effectiveness of these tablets. In almost all areas of Bangladesh, commercial alum and bleaching powder are available at the local markets. Commercial alum has been used in the past for purifying/disinfecting water although its effectiveness as a disinfectant and its optimum dose are not clearly known. Commercial bleaching powder is a common household disinfectant. These products could be effectively used for disinfecting water in the flood-affected areas. Thus there is an urgent need to determine the effectiveness and required dose of commercial alum and bleaching powder in disinfecting water during floods.

Boiling is a very popular means of disinfecting water at household level, especially where fuel is available. Often it is recommended that water be kept at boiling condition for at least 30 minutes before use. However, availability of fuel becomes a real problem during flooding and people usually find it difficult to boil water for a long time. In order to determine a reasonable time of water boiling for disinfecting, there is a need to check the effect of boiling time and temperature on the quality of the treated water.

The overall objective of the project was to develop low-cost technologies for treating water at household or small community levels in flood affected areas. For this purpose, water samples were collected from (a) WASA supply line (from taps in household and street hydrant), (b) hand pump tubewells, and (c) from open water bodies in flood affected areas. The specific objectives of this study were: (i) to evaluate the effectiveness and to determine the required optimum dose of alum in treating different types of polluted water, (ii) to evaluate the effectiveness and to determine the required optimum dose of chlorine in treating different types of polluted water, (iii) to evaluate the effectiveness of combined alum coagulation and chlorination in treating different types of polluted water, (iv) to determine the effect of boiling time and temperature on bacteriological quality of water, (v) to evaluate the natural decay of pathogens during storage of water, and (vi) to evaluate the strength of commercial chlorine disinfectants available in the market.

SIMPLE WATER TREATMENT METHODS

Virtually all the surface water sources and the flood-contaminated supply water contain easily detectable turbidity. Smaller suspended particles cannot be efficiently removed by plain sedimentation. Colloidal suspensions, which usually constitute the major part of a flood-contaminated water, are more stable as they do not agglomerate naturally. Coagulation is performed to make these colloidal particles unstable and force them to agglomerate. Although coagulation, settling and filtration can remove approximately 90% of the bacteria and viruses, disinfection is performed to kill or render harmless, pathogenic microorganisms.

Coagulation

The stability of colloidal suspension is principally governed by the large surface-to-volume ratio resulting from their very small size. In most natural waters the colloidal surfaces are negatively charged. When two colloids come in close proximity there are two forces acting on them. The electrostatic potential created by the halo of the counter ions surrounding each colloid reacts to repel the particles, thus preventing contact. The second force, an attraction force called the van der Waals force, supports contact. This force is inversely proportional to the sixth power of the distance between the particles and also decays exponentially with distance. It decreases more rapidly than the electrostatic potential, but is a stronger force at close distances.

In water treatment plants, chemical coagulation is usually accomplished by the addition of trivalent metallic salts such as $Al_2(SO_4)_3$ (Aluminum Sulfate) or

$FeCl_3$ (Ferric Chloride). Coagulation is accomplished by four mechanisms namely, ionic layer compression, adsorption and charge neutralization, entrapment in a flocculent mass, and adsorption and inter-particle bridging.

Ionic layer compression: The quantity of ions in the water surrounding a colloid has an effect on the decay function of the electrostatic potential. A high ionic concentration compresses the layers composed predominantly of counter ions towards the surface of the colloid. If this layer is sufficiently compressed, then the van der Waals force will be predominant across the entire area of influence, so the net force will be attractive and no energy barrier will exist.

Adsorption and charge neutralization: The nature of the ions is of prime importance in the theory of adsorption and charge neutralization. The ionization of aluminum sulfate (alum) in water produces sulfate anions (SO_4^{2-}) and aluminum cations (Al^{3+}). The sulfate ions may remain in this form or combine with other cations. However, the Al^{3+} cations react immediately with water to form a variety of aqua-metallic ions and hydrogen ions.

$$Al^{3+} + H_2O \rightarrow AlOH^{2+} + H^+$$
$$Al^{3+} + 2\,H_2O \rightarrow Al(OH_2)^- + 2\,H^{+-}$$
$$7\,Al^{3+} + 17\,H_2O \rightarrow Al_7(OH)_{17}^{4+} + 17\,H^+$$
$$Al^{3+} + 3\,H_2O \rightarrow Al(OH)_3 + 3\,H^+$$

The aqua-metallic ions thus formed become part of the ionic cloud surrounding the colloid and, because they have a great affinity for surfaces, are adsorbed onto the surface of the colloid where they neutralize the surface charge. Once the surface charge has been neutralized, the ionic cloud dissipates and the electrostatic potential disappears so that contact occurs freely. Overdosing with coagulants may result in re-stabilizing the suspension.

Sweep coagulation: The last product forming in the above equation is aluminum hydroxide, $Al(OH_3)$. The $Al(OH_3)$ forms amorphous, gelatinous flocs that are heavier than water and settle by gravity. Colloids may become entrapped in a floc as it is formed, or they may become enmeshed by its sticky surface as the flocs settle. The process by which the colloids are swept from suspension in this manner is known as sweep coagulation.

Intra-particle bridging: Large molecules may be formed when aluminum or ferric salts dissociate in water. Synthetic polymers may also be used instead of or in addition to metallic salts. These polymers may be linear or branched and are highly surface reactive. Thus several colloids may become attached to one polymer and several of the polymer-colloid groups may become enmeshed resulting in a settleable mass.

Generally, Jar test is performed to determine the optimum coagulant dose for particular water. Thus, it should be repeated if there is a significant change in the quality of water. The Jar tests are usually performed using a series of glass containers those hold at least 1 L and are uniform in size and shape. Normally, six jars are used with a stirring device that simultaneously mixes the contents of each jar with a uniform power input. Each of the six jars is filled to the 1-L mark with the water whose turbidity, pH, and alkalinity have been predetermined. One jar is used as a control while the remaining five are dosed with different amounts of coagulant at different pH values until the minimum values of residual turbidity are obtained. After chemical addition the water is mixed rapidly for about 1 minute to ensure complete dispersion of chemicals and then mixed slowly for 15 to 20 minutes to aid in the formation of flocs. The water is next allowed to settle for approximately 30 minutes, or until clarification has occurred. Portions of the settled water are then decanted and then tested to determine the remaining turbidity. Test results are then used to determine the quantity of coagulant to be used in water treatment.

Chlorination

A good disinfectant must be toxic to microorganisms at concentrations well below the toxic thresholds to humans and higher animals. Additionally, it should have a fast rate of kill and should be persistent enough to prevent re-growth of organisms in the distribution system. Disinfectants include chemical reagents such as halogen groups, ozone, and irradiation with gamma waves or ultraviolet lights.

Chlorination may be applied to water in gaseous form (Cl_2) or as salts [$Ca(OCl)_2$, NaOCl]. The reactions in water are as follows:

$$Cl_2 + H_2O \rightarrow H^+ + HOCl + Cl^-$$
$$Ca(OCl)_2 \rightarrow Ca^{2+} + 2\,OCl^-$$
$$NaOCl \rightarrow Na^+ + OCl^-$$

The hypochlorous acid (HOCl) and the hypochlorite ion (OCl^-) in the above equations are further related by the following relationship which is governed by pH and temperature. The sum of HOCl and OCl^- is called the free chlorine residual and is the primary disinfectant employed.

$$HOCl \leftarrow\quad \rightarrow H^+ + OCl^-$$

Boiling

Boiling is considered to be an easy and effective method for removal of pathogens from water. One of the most widely used household techniques, boiling involves heating the water for sometime at or around 100°C. Since almost all the pathogens in water survive and thrive in a temperature range of approximately 25-50°C, high temperature induces death in almost all the pathogens. However, there are some microorganisms that form spores and are resistant to high temperature. Thus, it is suggested that the water be boiled for a prolonged period.

Storage for Natural Decay of Pathogens

Intestine of warm-blooded animals provide the optimum conditions for survival, growth and reproduction of pathogens. As soon as they are excreted and find their way in aquatic environment, they face adverse environmental conditions for their survival and natural death occurs. If water is kept in a container thus blocking the supply of food and nutrient, a higher death rate should occur.

EXPERIMENTAL APPROACH

Sampling Program

In this study, water samples were collected from the available water sources in the flood-affected regions in and around Dhaka city. The sources were WASA supply line (taps in household and street hydrants), hand-pump tubewells, and open water bodies in flood-affected areas.

Development of Technologies

For treating water in flood-affected areas, 5 low-cost technologies were experimentally investigated to evaluate their performance. The technologies were (i) alum coagulation, (ii) chlorination, (iii) chlorination-alum coagulation, (iv) boiling, and (v) natural decay. The experimental procedures followed are described below.

Alum Coagulation

Dry alum [$Al_2(SO_4)_3 . 14H_2O$] was dissolved in distilled water to obtain a stock solution of alum of 5 mg/mL strength. To determine the optimum alum dose, 3 samples were collected from different locations of Dhaka city.

The usual procedure of establishing the optimum alum dose is to conduct Jar tests. But in reality, the results of Jar tests are not fully applicable in case of water treatment by individuals in flood-affected areas. Hence a simplified method was established and followed in determining the optimum dose for water treatment. The procedure involves the following steps: (i) Taking 500 ml water sample in each of 5 beakers, (ii) Adding alum solution to the beakers to obtain alum dosing of 100, 200, 300, 400 and 500 mg/L, (iii) Stirring vigorously with a bamboo/wooden stick for about 1 minute for uniform mixing, (iv) Stirring slowly for about 1 minute to facilitate floc formation, (v) Providing 30 minutes settling time for the flocs, (vi) Taking supernatant from each beaker at the end of the settling time and measuring turbidity, pH and faecal coliform of the collected supernatant.

After determining the optimum alum dose from these experimental results; another set of experiment was carried out to show the effect of contact time on removal of bacteria applying the optimum dose. Two sets of experiments were also conducted to evaluate the effect of contact time on bacterial removal at 500-mg/L alum dose using 2 samples. The contact time was varied from 15 minutes to a maximum of 120 minutes.

Chlorination

Collected samples from tap and hand pump tubewells from the flood-affected areas showed the presence of coliform but the water looked clean. Hence only chlorination was applied to these water samples to kill the pathogens in order to make them suitable for drinking. One such sample was treated with different chlorine doses. Bleaching powder (25% strength) was used to prepare a stock solution of chlorine. The dosing varied from 0.5 to 2.0 mg/L. After adding the doses to the beakers, each containing 200 ml water sample, the content was vigorously mixed with a glass rod. Allowing a contact time of 15 minutes, the treated water samples were tested for the presence of coliform and residual chlorine. The optimum dose of chlorine was determined from the experimental results.

Alum Coagulation-Chlorination

For clean water (i.e., water without suspended particulate, color, etc.) in flood-affected areas, chlorination was sufficient to produce drinking water. But depending on the magnitude of flood, clean water was not available in many areas and the floodwater was to be treated for drinking. As the floodwater contained turbidity, color and pathogens, chlorination and alum coagulation were simultaneously applied to the water. A total of 5 water samples were considered for chlorination-alum coagulation. The turbidity, color and faecal coliform concentrations of the water samples were measured. Then for each water sample, 500 ml was taken in a beaker and 1.0 mg/L of chlorine and 200-mg/L of alum (the optimum alum dose) were added and the same procedure as employed in the case of alum coagulation was followed. The turbidity, color, faecal coliform and residual chlorine concentrations of the treated water were determined.

Boiling

Chemicals may not be available to treat water in the flood-affected regions. So boiling may be the only option to kill the pathogens of the drinking water within a short time. Since fuel is scarce in the flood-affected areas, the minimum boiling required was investigated to save fuel. To fulfill the objective, a total of six water samples were boiled to reveal the effect of temperature and time on death rate of coliform. Floodwater, stagnant water and WASA water were heated upto boiling. For each case, the temperature of the water was measured and water sample was collected at different times. The water samples were analysed for coliform count in order to determine the effectiveness of temperature and boiling time on disinfection. Water was heated both in glass beaker and aluminum cooking pot (*dekchi*). For heating in beakers, multiple tube fermentation technique was used to determine the presence/absence of coliform. Membrane filtration method was used to enumerate the faecal coliform in the water samples.

Storage for Natural Decay of Coliform

Two flood water samples were tested for natural decay having initial faecal coliform count of 10,000 and 37,500 per 100 ml. The samples were kept open in the laboratory under natural environment. Faecal coliform count was determined on different days to determine their decay rate.

Strength Measurement of Locally Available Disinfectants

In this study, a survey was conducted on the availability of disinfectants in the local markets. It was found that disinfectants were available in two forms - chlorine tablet and bleaching powder. Since people of flood-affected area normally use these disinfectants, their strength (chlorine content) was determined. The commonly available disinfectants are described below.

Chlorine Tablets

In this study, different types of disinfectants, available in the market in “tablet” forms, were purchased and the strength of each type in treating water was determined separately. The brand names of the chlorine tablets procured from the market were (i) Halotab, (ii) Halazone, (iii) Hydroclonazone, and (iv) Wasserent keinun. Each type of tablet was dissolved in distilled water and the chlorine content was determined by standard procedure.

Bleaching Powders

Various types of bleaching powder available in the local markets were procured and the chlorine content of each type of the bleaching powder was determined by standard method after dissolving it in distilled water. The tested bleaching powders include Navy bleaching powder, Azad bleaching powder and SP Company's bleaching powder.

RESULTS AND DISCUSSION

Alum Coagulation

To determine the optimum alum dose, 3 water samples of flood-affected zones were collected and tested for alum coagulation. The pH, turbidity and coliform concentrations of the collected samples are shown in Table 1.

Figure 1 presents the effect of alum dose on residual turbidity of treated water samples. From the figure, the optimum alum dose was found to be about 200 mg/L for all the three different samples tested.

Table 1: Characteristics of Water Samples used for Determining Optimum Alum Dose

Sample No.	Source of water	pH	Turbidity (NTU)	Faecal Coliform (#/100 mL)
1	Flood water	7.2	147	6,000
2	Buriganga River, Nawabganj	6.4	19	60,000
3	Buriganga River Sawarighat	5.8	23	70,000

The pH change of the treated water samples with the variation of alum dose is shown in Fig. 2. The pH values decreased due to the formation of hydrogen ion as a result of chemical reaction with water. The higher was the alum dose, the more hydrogen ions were produced, resulting in lower pH value. In case of floodwater, the pH change was smaller than that of the river waters. It indicates that the floodwater had higher alkalinity value in comparison with that of the river waters.

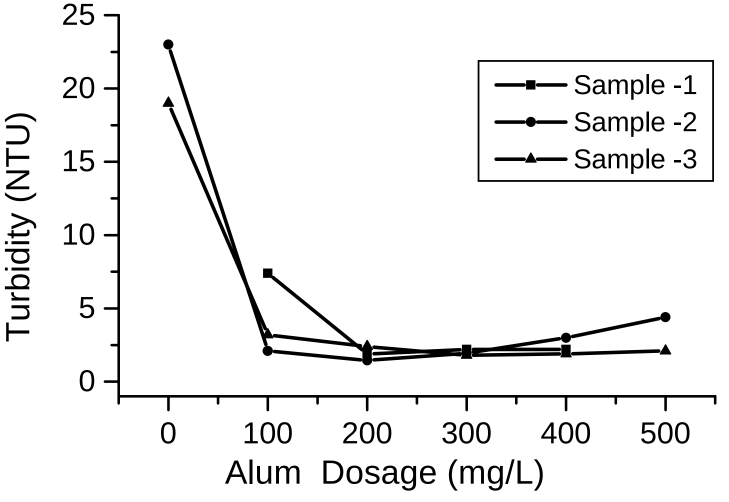

Figure 1: Effect of alum dose on residual turbidity of water

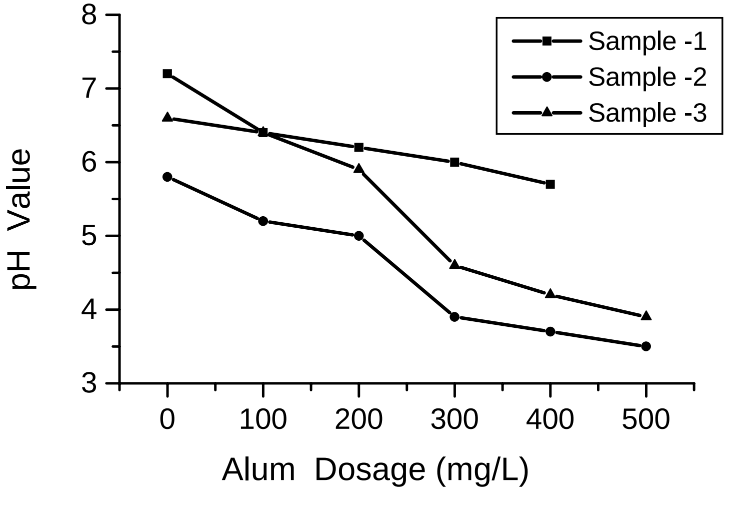

Figure 2: Change of pH value with the variation of alum dose

The relationship between the removal of faecal coliform and the alum dose for 30-minute contact time is shown in Fig. 3. The removal was higher with the increase of alum dose. It appears that the removal was greatly affected by the composition of the raw water. In case of significant reduction in pH value due to the addition of alum, a high degree of removal was attained. It appears that the acidic condition resulted in higher removal efficiency. However, complete removal of faecal coliform was not attained in any case.

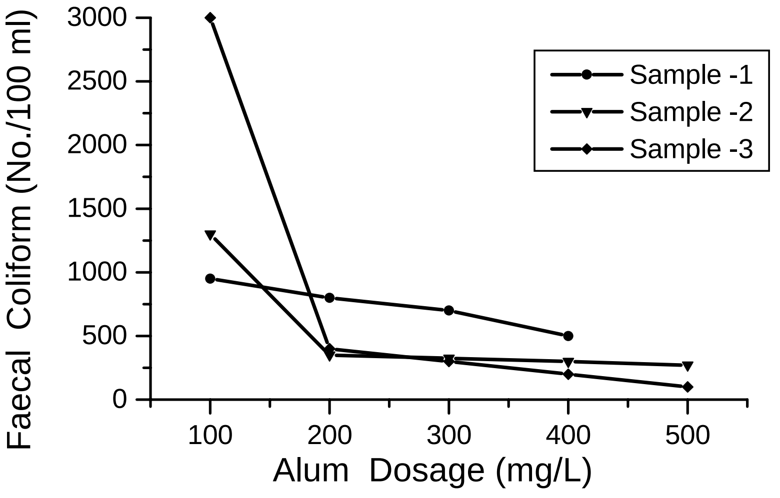

Figure 3: Effect of alum dose on removal of faecal coliform

The effect of settling time on bacteria removal at two different alum dosing is presented in Fig. 4. It shows that the removal rate was very high initially but then slowed down. The larger and heavier flocs settled quickly and removed most of the microorganisms. Settling of micro-flocs occurred slowly and longer contact time at acidic condition was mainly responsible for subsequent removal. It was also noticed that there was a difference in the removal rate between the two water samples at the same alum dose. It appears that the bigger change in pH value produces higher removal rate. However, long settling time (2 hours) and high alum dose (500 mg/L) could not remove the faecal coliform completely.

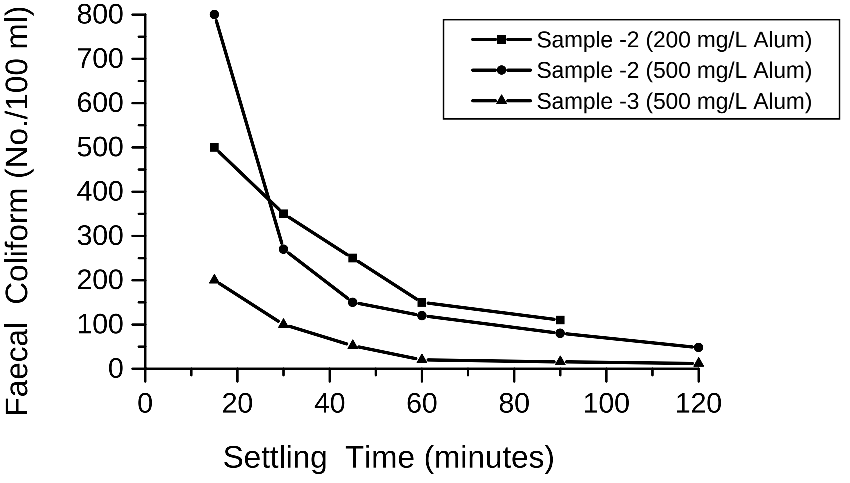

Figure 4: Effect of settling time on the removal of faecal coliform

Chlorination

The effect of chlorination on tap water is presented in Fig. 5. The initial faecal coliform count of the raw water was 210 no./100-mL and chlorine doses of 0.5 to 2.0 mg/L were applied. A contact time of 20 minutes was maintained. The figure shows that the residual chlorine increased with higher chlorine dose without showing any break point. No faecal coliform was detected at these applied doses. It should be noted that drinking water should not contain more than 0.2 mg/L of chlorine in order to avoid possible adverse health effects. Application of 0.5 mg/L of chlorine dose produced 0.08 mg/L of residual chlorine. Hence, from the figure, the allowable dosing of chlorine can be taken as 0.5 to 1.0 mg/L. The low dose of 0.5 mg/L should be applied to apparently clear water and the high dose of 1.0 mg/L should be applied to highly turbid floodwater.

Alum Coagulation-Chlorination

To treat floodwater having high turbidity, color and pathogens, both chlorination and alum coagulation were applied. The turbidity, color and faecal coliform concentrations of the raw water samples are presented in Table 2.

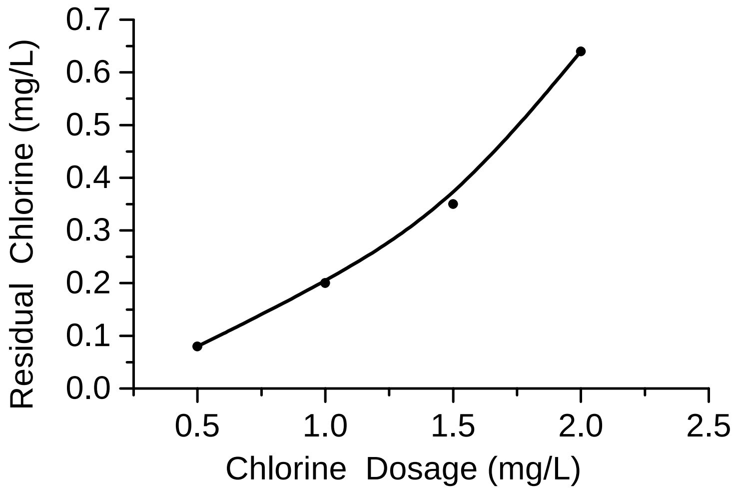

Figure 5: Effect of chlorine dose on residual chlorine

Table-2: Characteristics of Floodwater Treated by Chlorination-Alum Coagulation

Sample Designation	Turbidity (NTU)	Color (TCU)	Fecal Coliform (No. / 100 ml)
A	90.0	123	37500
B	12.2	49	12500
C	20.0	56	34000
D	30.0	115	20000
E	57.0	125	8000

The results of turbidity removal are shown in Fig. 6. It is evident that the turbidity in the range of 12 to 90 NTU was effectively removed (less than 5 NTU, WHO guide line value), resulting in highly transparent water. It should be mentioned that the drinking water standard of turbidity is 10 NTU according to Environment Conservation Rules (GOB, 1997).

The color removal through the process of chlorination-alum coagulation is shown in Fig. 7. The color removal was very effective for 2 samples (sample A and B), while in the cases of other 3 samples, the process failed to bring the color of the treated water below 15 TCU, the Bangladesh standard for color (GOB, 1997).

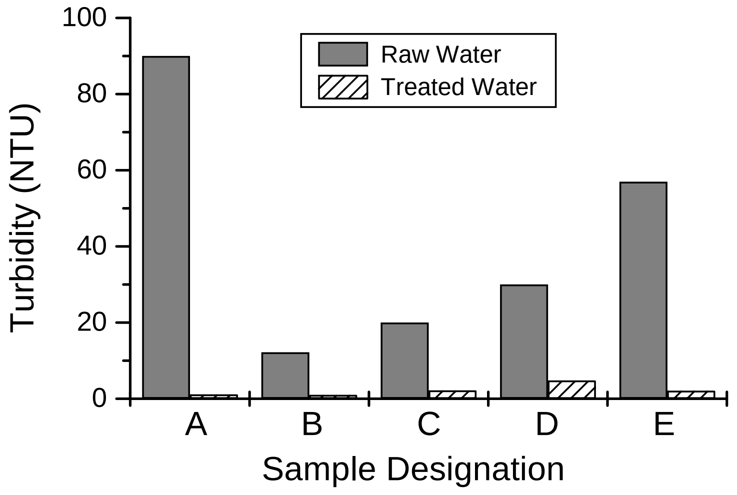

Figure 6: Removal of turbidity through alum coagulation-chlorination

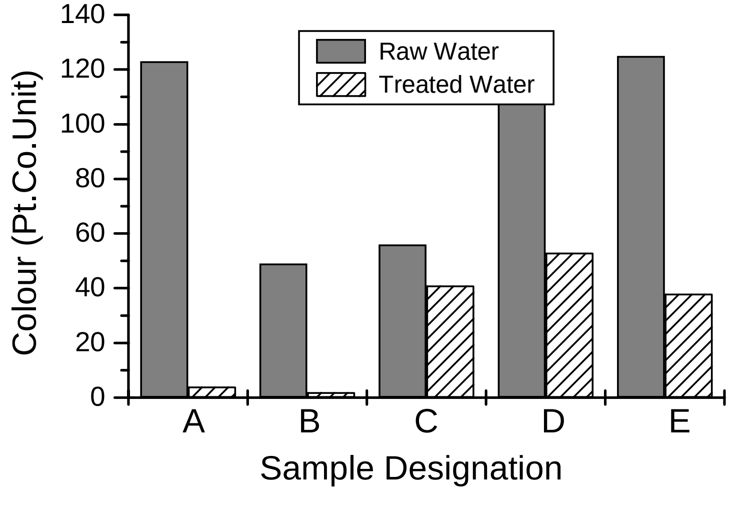

Figure 7: Effect of chlorination-alum coagulation on color removal

The faecal coliform removal and residual chlorine present in the treated water after the coagulation-chlorination process are presented in Table 3.

Table 3: Removal of Faecal Coliform by Chlorination- Alum Coagulation

Sample Designation	Faecal Coliform (No. / 100 mL)		Residual Chlorine (mg/L)
	Raw Water	Treated Water	
A	37,500	0	0.58
B	12,500	0	0.51
C	34,000	0	0.73
D	20,000	0	0.65
E	8000	0	0.47

Note: *Cl_2 = 1 mg/L, Alum = 200 mg/L, Contact Time/Settling Time = 30 min.*

From Table 3, it is evident that irrespective of the concentration of faecal coliform and other constituents initially present in the raw water samples, the process removed faecal coliform from the water samples completely. However, in all the treated samples the residual chlorine concentrations were more than 0.2 mg/L (drinking water standard). It can be concluded that the chlorine dose should be 0.5 mg/L when applied with alum coagulation. Since alum coagulation alone reduced the faecal coliform significantly, low dose such as 0.5 mg/L of chlorine may be adequate for floodwater.

Boiling

The effect of boiling time on the temperature for two water samples (flood water and tap water) is shwon in Fig. 8. The floodwater started to boil at a temperature of 85° C after heating the water for 35 minutes. The tap water began to boil at 87°C after 35 minutes of heating. For both the samples, test results showed the presence of coliform at 40°C temperature, however at 80°C temperature, coliform was not detected. The corresponding heating times were 17 minutes and 23 minutes, respectively.

Fig. 9 shows the relationship between the boiling time and the temperature of water for boiling in aluminum cooking pot (*dekchi*) using gas burner for two water samples (flood water and tap water). It was observed that the samples started to boil at around 98° - 100°C after 20 minutes of heating. A comparison between Figs. 8 and 9 reveal that rate of temperature rise in an aluminum pot was much higher than that in a glass beaker. This was simply because aluminum is a good conductor of heat while glass is a bad conductor and the aluminum pot was under direct heating while the glass beaker was placed in a water bath.

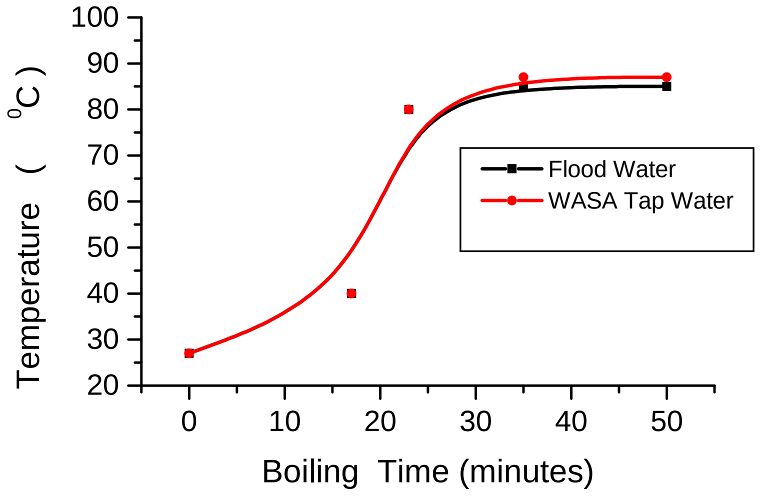

Figure 8: Effect of boiling time on water temperature

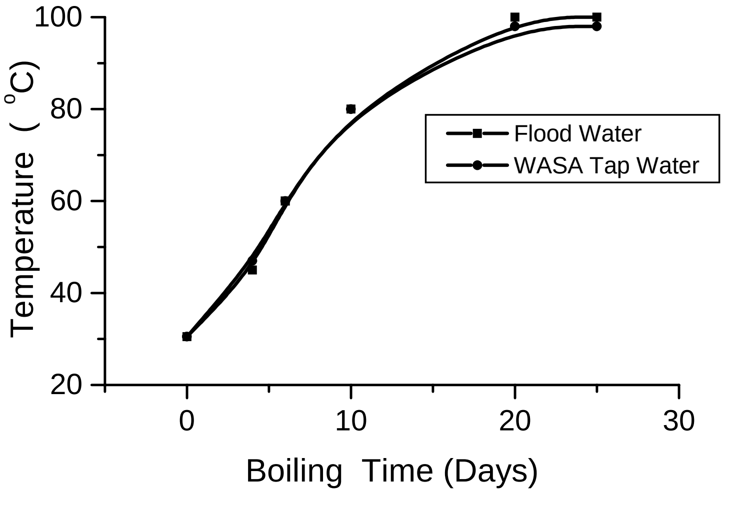

Figure 9: Effect of boiling time on water temperature

The effect of temperature of water on the removal of faecal coliform for the two samples is presented in Table 4. It is seen that faecal coliform was not detected in any sample when the temperature was higher than 60°C. The corresponding boiling time was 6 to 7 minutes. In practical application, it is difficult to monitor either the temperature of water or the duration of heating. So it is safe to boil a water sample upto the boiling point to ensure total removal of coliform.

Table 4: Variation of Faecal Coliform Concentration with Temperature (T) of Water.

Type of water	Faecal Coliform Count (No./100mL)				
	T = 30.5°C	T = 45°C	T = 60°C	T = 80°C	T = 100°C
Tap water	10	144	0	0	0
Flood water	80,000	80,000	0	0	0

Natural Decay of Coliform

The results of natural decay for two samples are presented in Fig.10. It was observed that the decay rate was very high initially and then slowed down with time. It is seen that storing of water under natural environment even for 7 days was not sufficient for 100% removal of the faecal coliform. It proves that natural decay is a very slow process and is not a practical method to obtain pathogen-free water.

Strength of Available Disinfectants

A total of four different types of chlorine tablets and three kinds of bleaching powder were tested for the presence of total chlorine. The results are shown in Table 5.

Table 5: Chlorine Content of Commercial Disinfectants

Type of disinfectant	Trade Name	Total Chlorine (mg per tablet)	Total Chlorine (%)
Chlorine Tablet	Halotab	3.0	-
	Halazone	0.92	-
	Hydroclonazone	1.11	-
	Wasseren keinun	0.02	-
Bleaching powder	SP company	-	0.4%
	Navy	-	1.4%
	Azad	-	0.85%

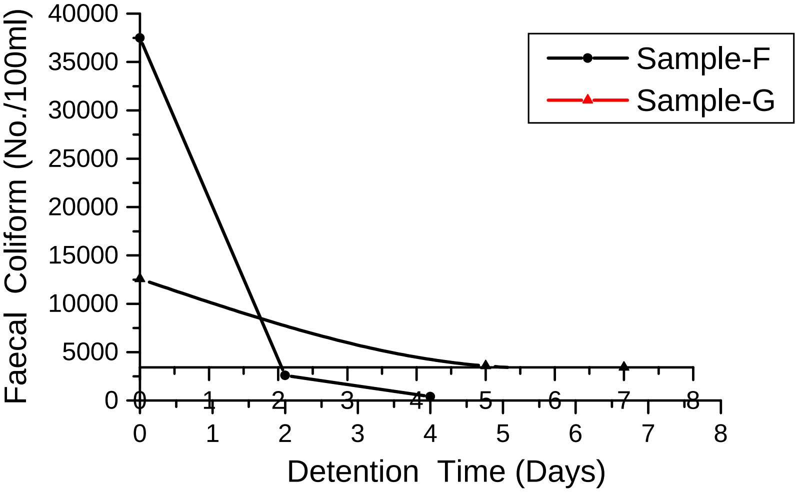

Figure 10: Effect of detention time on natural decay of faecal coliform

It is seen from Table 5 that the chlorine content of the tablets varied from 0.02 to 3.0 mg per tablet. Manufacturing and expiry dates were not mentioned for any of the brands tested. Since chlorine is volatile, the shelf life of the tablets was the prime reason for such a wide variation in strength. Other reasons might be the variations in constituents, production method and packaging of the tablets. *Halotab*, a local product, was the best in terms of strength, possibly because it was recently produced.

The bleaching powders showed a large variation in chlorine strength, which varied from 0.4 to 1.4 %. Manufacturing and expiry dates were not written on the packets. Constituents as well as shelf life are the possible reasons behind the variation. It appears that the available disinfectants are not reliable for proper dosing. Smell of chlorine-based disinfectant may be a crude indicator of the strength - the more intense the odor, the higher the chlorine content.

CONCLUSIONS

A variety of simple techniques were studied to develop low-cost technologies for water treatment in flood-affected areas. Boiling was found to be the most effective method of killing almost all types of pathogens. Heating upto the boiling point was found to be sufficient for this purpose. Chlorination was found to be quite effective in killing pathogens at a chlorine dose of 0.5 -to1.0 mg/L and 30-minute contact time. Alum dosing at 200 mg/L could effectively reduce the turbidity of floodwater but it could not make the water bacteria-free even at much higher doses. Colored and turbid floodwater could be treated with application of chlorination and alum coagulation simultaneously. For this purpose, the required alum dose was found to be 200 mg/L and the chlorine dose 0.5 mg/L. The settling time/contact time to be provided was found to be 30 minutes. The quality of the available chlorine disinfectants varied widely mainly due to variation in shelf life. The strength may roughly be assessed by smelling. The quality of local chlorine tablets was found to be better than that of foreign tablets.

The low-cost technologies developed through this study can be conveniently used to treat contaminated water during floods/post flood period. The application procedures can be summarized as follows: (a) Heat water upto the boiling point. There is no need to heat the water beyond the starting of boiling. It is the most convenient method of killing pathogens at household level; (b) Add chlorine tablet or bleaching powder solution to tubewell water or water from distribution line or clean floodwater. Mix thoroughly and wait for 30 minutes. The water is then suitable for drinking. The chlorine dosing requirement is 0.5 - 1.0 mg/L, depending on the turbidity of the water. For apparently clear water, use 1 fresh Halotab (a local chlorine tablet containing 3.0 mg chlorine) for 6 L water or 1-teaspoon (5-mL) bleaching powder solution for 10 L water. The solution is to be prepared by dissolving 1-teaspoon (5 gm) medium strength bleaching powder (chlorine content = 10%) in 2 glasses (0.5 L) of water. Preserve this solution in a green/brown bottle with stopper; (c) Treat the water of underground reservoir by adding 5 L bleaching powder solution (10 teaspoon of 10% strength) per 10,000 L water and mix uniformly. Wait for about 1 hour and then use the water; (d) Complete removal of pathogens from water can not be achieved by alum treatment. Treat turbid/colored floodwater by adding both alum and chlorine. Dissolve 1-teaspoon (5 gm) alum powder in 25 L floodwater in a suitable container (e.g., a bucket fitted with a tap). Then dissolve 4 fresh *Halotab* in the water or add 2.5 teaspoon bleaching solution prepared as described earlier and preserved in a bottle. Stir the floodwater vigorously for 1 minute and then slowly for 1 minute. Wait for 30 minutes and collect/decant the clear water leaving sludge at the bottom of the container. This water is suitable for drinking; (e) The hand-pump tubewells in flood-affected areas need a post flood treatment. Prepare 10 L bleaching powder solution (5 teaspoon of 10% strength) for one tubewell. Open the seat (foot) valve of the tube well and add the bleaching solution. Wait for 12 hours and then start pumping. Discard all the water as long as the odor of chlorine is detected in the water. Then the tubewell water is suitable for drinking.

REFERENCES

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