Assessment of a membrane drinking water filter in an emergency setting

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ABSTRACT

The performance and acceptability of the Nerox^{TM} membrane drinking water filter were evaluated among an internally displaced population in Pakistan. The membrane filter and a control ceramic candle filter were distributed to over 3,000 households. Following a 6-month period, 230 households were visited and filter performance and use were assessed. Only 6% of the visited households still had a functioning filter, and the removal performance ranged from 80 to 93%. High turbidity in source water (irrigation canals), together with high temperatures and large family size were likely to have contributed to poor performance and uptake of the filters.

Key words | acceptability, emergency, household water treatment, Nerox^{TM} filter, use

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INTRODUCTION

Over 700 million people worldwide lack access to safe drinking water (UNICEF & WHO 2012); poor-quality drinking water is an important contributing factor to high childhood diarrhoea and mortality in children under 5 years of age. High operation and maintenance costs make the provision of drinking water for all through centralized, piped water systems unattainable in the short-term future. Immediate interventions are thus required to support those without access to safe drinking water. Household water treatment (HWT) has been recognized as an effective means of providing safe drinking water at low cost (Sobsey *et al.* 2008). HWT is considered especially effective as it not only addresses source contamination, but also tackles recontamination during transportation and storage (Thompson *et al.* 2003). During emergencies the provision of clean water is a top priority as waterborne epidemics can spread quickly and cause high mortality. There are many HWTs including: boiling, chemical disinfection, flocculation, straining and filtering of water, each of which has specific advantages and disadvantages depending on local conditions and the experience of the expected users.

The London School of Hygiene and Tropical Medicine was asked by Oxfam to evaluate the performance and user acceptance of the Nerox™ drinking water filter, a gravity filter that uses a polymeric membrane as a microbial barrier. Oxfam felt that the Nerox™ filter offered a seemingly effective treatment system but wanted an independent evaluation of the filter's acceptance by the community, ease of use, durability and longer-term effectiveness.

METHODOLOGY

The field evaluation was originally planned to take place over a 6-month period from July to December 2007, with monthly household visits and water quality testing. However, the security situation, which had deteriorated quickly as a result of local and national events, prevented the field teams from conducting the field evaluation as planned. Nerox™ drinking water filters and control ceramic filters were distributed in September 2007, but only in March/April 2008, after the Pakistani elections, and based on a modified study protocol, did the evaluation assessment take place.

Study area

The evaluation survey was conducted in the districts of Nasirabad and Jaffarabad, Baluchistan, Pakistan among

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internally displaced households, which had fled the fighting between Baluchi tribesmen and the Pakistan army in the neighbouring district of Dera Bugti.

Of the internally displaced population (IDP) over 40% had no adequate shelter, and were reliant on informal shacks made of local materials. The remaining population has been housed in tents provided by Oxfam. They often lived in cramped conditions with two to three families sharing a tent.

In large parts of Baluchistan Province, groundwater is unfit for consumption as a result of high natural salinity, and in both study districts irrigation canals served as the main source of water for all domestic uses, including drinking. About 10% of households relied on seepage water from irrigation canals that had formed fresh groundwater lenses close to irrigation canals, and was extracted through wells and hand pumps, or people collected water directly from village ponds fed by irrigation canals. During March–April, most households switch from irrigation canals to pond water, as a result of the closure of irrigation canals for annual maintenance. Irrigation canals in Pakistan are prone to contamination resulting from wastewater disposal by urban centres located upstream, from local contamination through washing and bathing of cattle, and from return flows from agricultural land. *Escherichia coli* concentrations in irrigation water in the southern Punjab were found to be high with typically over 1,000 *E. coli* per 100 ml (Van Der Hoek *et al.* 2001).

IDPs were found to live in close proximity to irrigation canals and during interviews, distance and availability of water was not reported as a problem. The responsibility for fetching water rests with women and girls, and they reported that no treatment was provided to drinking water other than keeping the water in clay pots for some time until sand and other suspended particles had settled down. Water was considered of poor quality, and some attributed health problems like diarrhoea and skin diseases to the water quality. Families which used hand pumps to extract drinking water mentioned that groundwater was extremely salty.

The interventions

Nerox™ filter

The Nerox™ filter (A-Aqua, Oppegaard, Norway) is a gravity water filter system (Figure 1) that employs a 0.28 μm membrane to mechanically remove bacteria, cysts and helminths from water of unknown microbial quality. Although different websites make claims about the removal performance of *E. coli*, total coliforms, faecal coliforms, *Salmonella* spp., metals, certain organic compounds found in fertilizers, herbicides and pesticides, the official website makes no claims regarding treatment performance. In so far as the Nerox™ filter employs microfiltration, it also reduces turbidity, thereby improving the water's appearance. The membrane is contained in a hard plastic housing measuring 20 × 16 × 2.5 cm. Source water passes into the housing and through the surface of the membrane; product water is delivered via a 1.95 m plastic tube. The basic filter unit, identified as the 'Nerox-02' consists of the housing, membrane, tube, sponge for cleaning the membrane surface, and stopper. In this evaluation the basic filter was accompanied by two collapsible water containers (a 15-litre 'U-Bag' bag for raw source water and a 10-litre

Figure 1 | Diagram describing the use of the Nerox™ filter.

'U-Can' bag with cap for the treated drinking water), a small hand pump for establishing flow, a screw cap and two tube clips (the 'Nerox-2 emergency drinking water kit', product no. 5800-5). The filter assembly has to be placed inside the raw water container, which has to be placed a minimum of 30 cm higher than the drinking water container.

Households have to start the filtering process by pumping the air from the tube to create a siphon. When flow has been established, the end has to be placed into the product water container. Based on the manufacturer's instructions, the membrane has to be cleaned every 3–7 days by stopping the flow, opening the membrane housing, filling the raw water vessel with treated water, and gently wiping the membrane on both sides with the sponge provided. The cleaning instructions also recommend that water containers are disinfected and that the filter system is cleaned by filtering 8 to 10 litres of chlorine-treated water through the membrane filter. It has been claimed that the capacity of the membrane is 2,000 to a maximum of 2,500 litres; however, that would depend on the quality of the raw water. The flow rate was described in the specifications as 15–25 litres of water per day. The cost of a Nerox™ filter was £25 (2008).

Ceramic candle filters

For comparison purposes, the Nerox filters were deployed with Oxfam's standard household water filter (Figure 2). The filter is manufactured from two plastic buckets, one stacked on top of the other. Two Stefani® (Ceramica Stefani, São Paulo, Brazil) 12-cm porous ceramic filters (commonly referred to as 'candles') are threaded through rubber washers, a hole in the bottom of the top bucket and the lid of the bottom bucket. When the top bucket is filled with raw water, it passes through the ceramic candles into the bottom bucket where it is accessed solely by means of a tap. A single candle can produce roughly 24 litres per day, and according to the manufacturer a candle has a life of 6 months. The Stefani candles have been shown to reduce faecal bacteria by 4 log (99.99%) (Clasen & Boisson 2006). The entire set-up, including candles is estimated to have cost around £12 (2008).

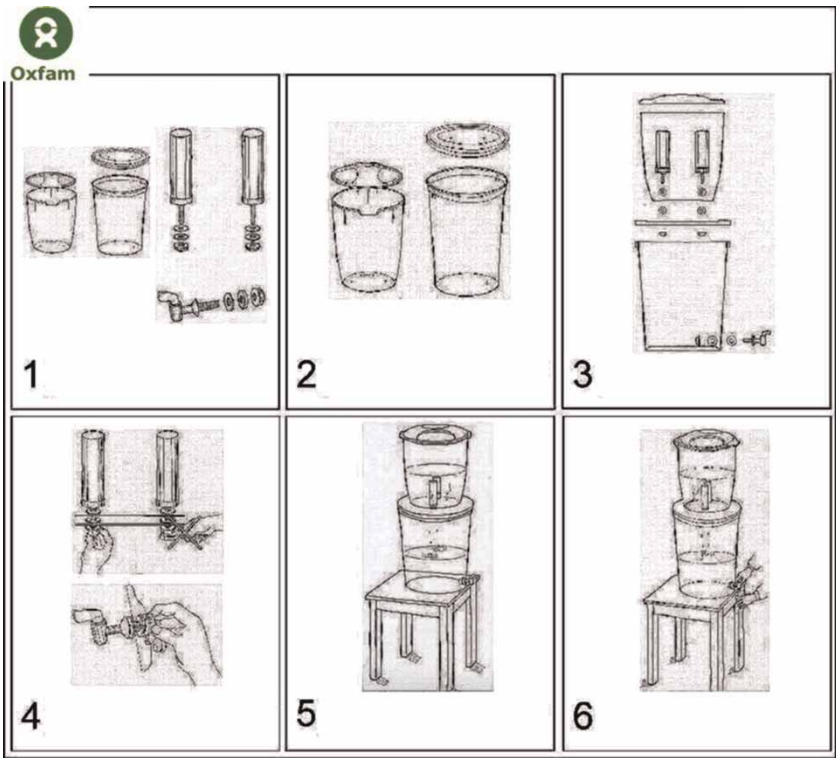

Figure 2 | Diagram showing the use of ceramic filters.

Data collection

In September 2007, 2,997 families received a Nerox^{TM} filter and a random 78 families received a ceramic candle filter. The filters were distributed as part of a food distribution scheme; training on the usage and cleaning of the filters was provided by a local non-governmental organization (NGO). Training was done in community groups and was targeted separately at men and women. In March 2008 (6–7 months later) 210 households that had received a Nerox^{TM} filter and 20 households that had received a ceramic candle filter were randomly selected from the distribution list and visited. During each household visit, the filter was physically examined, and a short worksheet to report observations about its condition was completed. With the help of a standardized questionnaire an assessment was made regarding the use and maintenance of the filter, the period of use, and the considered benefits and problems with the use of each filter type. In case a filter was still in use a water sample was collected from both the treated water and the original source and analysed for thermotolerant coliforms (TTCs) and turbidity.

Samples were aseptically collected in a sterilized 125-ml bottle, and kept on ice until analysis. Samples were analysed within 4 hours of collection. A first sample was collected from the treated water, following which a sample was collected from the source water. Water samples were analysed using the membrane filter in an Oxfam Delagua portable incubator (University of Surrey, Guildford, UK). Samples were passed through a 0.45-μm membrane filter (Millipore, Bedford, USA) and incubated on membrane lauryl sulphate media (Oxoid Limited, Basingstoke, UK) at $44 \pm 0.5\,^{\circ}C$ for 18 hours. Yellow colonies were counted and recorded as individual TTCs; if a plate produced a number of colonies that were too numerous to count, the count was assigned a value of 300 TTCs, as this was considered the maximum number of colonies that could be reliably counted on the used plates.

RESULTS

The average household consisted of 7.2 family members, with families ranging from two to 23 people. The main drinking water source was irrigation water with over 85% of all respondents using either irrigation canals or ponds filled by irrigation water. Seepage water from irrigation canals was only used by the group that used the Nerox^{TM} filters (Table 1). The large majority of households collected water once a day, and used the filters either exclusively to produce water for drinking, or for both drinking and cooking. Close to 100% of the population under study reported to have cleaned their filters either every day, or every second day.

Out of the 210 households that had received a Nerox^{TM} filter 6 months previously 10% of them were found to be still in use, while none of the ceramic filters was found in use. Close to 70% of the total study population stated that they had abandoned the use of the filter at least 1 month before the survey, while close to a quarter stated that they had stopped using their filters over 3 months ago. Out of the 21 households still using the filters, nine (43%) used seepage water from irrigation canals for drinking water. Membrane filters and/or bags were found available in less than 40% of all households (Table 2). On closer inspection, only 14 (6.7%) of the membrane filters were found in working condition, 27 (12.8%) of the bags delivered with the membrane filters were still intact, and 24 (11.4%) tubes connecting the membrane filters with the bags could still convey water. This meant that only 12 (5.7%) filter units on visual inspection were still considered to be in working condition. Out of the 14 households with a working filter, nine (64%) households relied on seepage water.

None of the households which had received ceramic filters still used them, though the metal buckets, and in many cases the ceramic filters, were still available in the households. In 30% of the households the ceramic filters had broken; this was associated with the tightening of the saturated filter to prevent leakages from the top to the bottom vessel (Figure 3). Based on the study participant interviews, it was suggested that filters did not usually last more than 2 months.

Water quality

During the survey, 19 of 21 working filters were tested, and paired water samples were collected and examined for TTC and turbidity. The turbidity of the surface water sources – pond, irrigation canals and well water – ranged from 53 to 276 nephelometric turbidity units (NTU) (Table 3), with a

Table 1 | Water use characteristics of both filter groups

	Ceramic filter (*n* = 20)	Nerox filter (*n* = 210)	Significance test
Type of water supply			
Irrigation canal	13 (65%)	182 (87%)	$\chi^2 = 51$ $P < 0.001$
Seepage water (well or hand pump)	–	25 (12%)	
Village pond	7 (35%)	3 (1%)	
What do you use the filtered water for?			
Drinking	11 (55%)	152 (72%)	$\chi^2 = 2.7$ $P = 0.10$
Drinking + cooking	9 (45%)	58 (28%)	
How often do you fetch water?			
More than once a day	3 (15%)	16 (8%)	$\chi^2 = 2.3$ $P = 0.69$
Once a day	17 (85%)	183 (87%)	
Every second day	–	11 (6%)	
How often did you clean the filter?			
Once per day	17 (85%)	192 (91%)	$\chi^2 = 3.1$ $P = 0.69$
Every second day	3 (15%)	12 (6%)	
Once a week	–	4 (2%)	
Once a month	–	1 (0.5%)	
Never	–	1 (0.5%)	
When did you stop using the filter?			
Still using it	–	21 (10%)	$\chi^2 = 10.2$ $P = 0.07$
2 weeks to 1 month ago	5 (25%)	41 (20%)	
1 month to 2 months ago	7 (35%)	47 (22%)	
2 months to 3 months ago	6 (30%	50 (24%)	
More than 3 months ago	2 (10%)	52 (24%)	

Table 2 | Number of filter parts found in household and problems reported for the Nerox™ filter systems

	Found in the household	Still functioning	Reported problem(s)
Filter	78 (37.1%)	14 (17.9%)	Blue casing missing (16.7%) Filter is filled with dirt (37.2%) Few small holes (23.1%). Many large holes (37.2%)
Bags	76 (36.2%)	27 (39.5%)	Bags torn/Holes in bags (60.5%)
Tubes	62 (29.5%)	24 (38.7%)	Blocked (38.7%) Ruptured (22.6%)

Figure 3 | Broken ceramic filter.

maximum turbidity concentration found for irrigation water of over 900 NTU. TTC concentrations in source water ranged from 138 to 600 CFU/100 ml. Seepage water from irrigation canals retrieved by hand pump was of the best quality with a mean turbidity of 10 NTU, though TTC concentrations were high with a mean of 356 colony-forming units (CFU)/100 ml. The average TTC removal for the

Table 3 | Key water quality indicators for source water and household water following treatment by a Nerox™ filter

Place	n	Mean turbidity (NTU)	Geomean TTC (CFU/100 ml)	Mean TTC Removal (%)
Irrigation canal	8	276	365	80%
Household		19	74	
Well	7	53	138	84%
Household		<5	21	
Pond	1	130	600	92%
Household		<5	50	
Hand pump	3	10	356	93%
Household		<5	24	

Table 4 | Reported advantages and disadvantages of both types of filter

	Ceramic filter ($n = 20$)	Nerox filter ($n = 210$)	Significance test
Water is cleaner	12 (60%)	155 (73%)	$\chi^2 = 1.7$, $P = 0.19$
Water tastes better	4 (20%)	125 (60%)	$\chi^2 = 11.6$, $P < 0.001$
Water is more healthy	17 (85%)	139 (66%)	$\chi^2 = 3.0$, $P = 0.09$
Takes too long to filter water	16 (80%)	164 (78%)	$\chi^2 = 0.4$, $P = 0.83$
Filter is difficult to clean	9 (45%)	49 (23%)	$\chi^2 = 4.5$, $P = 0.03$
Filter needs to be cleaned too often	6 (30%)	51 (24%)	$\chi^2 = 0.3$, $P = 0.57$
Filter delivers not enough water	6 (30%)	71 (34%)	$\chi^2 = 0.11$, $P = 0.73$
Bags are difficult to carry/heavy	–	61 (29%)	
Water becomes too hot	–	173 (82%)	

Nerox™ filter ranged from 80% to 93% depending on the water source used, and the difference between source and household water was found to be significant for all water sources with the exception of pond water, as a result of the small sample.

User views

Both types of HWT device were appreciated by the recipients as all the study participants mentioned at least one advantage of using the filters (Table 4). Although both groups mentioned that their drinking water following treatment was of better quality, and would contribute to better health, a significantly larger number of study participants (20 vs. 60%) mentioned that their drinking water tasted better following the use of the Nerox™ filter. Study participants claimed that both filter types were unable to deliver enough water (both in quantity and time) for household use. The high turbidity in the drinking water sources meant that people cleaned the filters almost every day, which both groups of filter users found to be an inconvenience. A particular problem associated with the use of the Nerox™ filters, and the accompanying bags was that they were perceived as heavy and difficult to carry, and were likely to tear when hung on a nail. Over 80% of Nerox™ filter users complained that the water in the treatment bags was too hot as a result of exposure to the sun for long periods. These high temperatures sometimes resulted in melting of plastic bag handles, but more generally made the water unpalatable.

DISCUSSION

This study evaluated the Nerox™ emergency filters under field conditions in Pakistan. Following 6 months of use, only 10% of the filters were still found to be in use, and only 6% were found to be in working condition. None of the filters produced water free of TTC. A large proportion of the filters seemed to be abandoned within 3 months of distribution, and several problems related to durability were reported by the users. The high turbidity in the original source water is likely to have played a role in the performance of the filters.

Performance, use and acceptability

Given the fact that a water sample was only collected at 6 months, and not at regular intervals since distribution of the filters, it is hard to judge the actual performance of the different filters, or when they stopped performing. However, no functioning ceramic filters were found, and those Nerox™ filters that were still in use did not provide drinking water up to WHO drinking water standards (WHO 2011). No other studies evaluating the field performance of Nerox™ filters were found, and as a result no comparison is available; however, past studies on field performance of ceramic filters have reported bacterial count reductions ranging from 64 to 100% (Clasen *et al*. 2006; Albert *et al*. 2010; Luoto *et al*. 2011), and Nerox™ filters fit into this range.

The Nerox™ filter specification states that the filter has a lifetime between 2,000 and 2,500 litres filtered, and between 15 and 25 litres per day. Assuming a 2-litre water consumption and average family size of seven, the filters under normal circumstances should have lasted between 140 and 180 days. Almost 50% of the households indicated that they had stopped using the filters over 2 months ago, which would indicate a use of 4 months or less. During this study no visits occurred between distribution of the filters and the survey 6 months later, and it is therefore very hard to assess how long the filters had actually been used. The reported period that the Nerox™ filter was used is likely to be subject to courtesy bias, if the recipients might have mentioned a longer period of usage in order not to disappoint the implementing agency, or recall bias if they simply forgot exactly when they stopped using the filter. However, the fact that filter units or the accompanying plastic bags could be found in only 40% of households is likely a good indicator that households had stopped using the Nerox™ filters some time ago. Although the sample size was small, the ceramic filters showed a very similar use pattern, with 75% of the study participants having abandoned the use of the filters following a maximum of 5 months of use.

The majority of the study participants appreciated the visual improvement in water quality and an improved taste, which was associated with a perceived positive health impact. However, many problems were reported too. The long time needed to filter water, and the small quantities provided per day were reported by almost all study participants as problematic. Over 90% of the study participants cleaned the filters, either daily or every second day, although the manufacturer states that every 3 to 7 days should be sufficient. The frequent cleaning of the filter could have been a result of the high turbidity of the source water; with irrigation water especially showing very high turbidity levels. This will have likely blocked the filters (Figure 4), slowed down water provision and resulted in frequent cleaning of the filters. The missing filter casings and the high number of membrane filters with small and large holes would point at wear and tear as a result of the frequent cleaning of the filters and would have rapidly made the filters useless.

Figure 4 | Blocked Nerox™ membrane filter.

According to the manufacturer, the ceramic filters have a lifetime of at least 6 months, though none of the filters was still in use at the time of the survey. A study in Bolivia found 73% of filters still in use after 9 months, and 49% were still found in use in the Dominican Republic 16 months following introduction (Clasen *et al*. 2006, Clasen & Boisson 2006). In Bolivia 8% of filters had broken over 9 months (Clasen *et al*. 2006), 27% in the Dominican Republic over a 16-month period compared with the 30% in less than 6 months in this study. This could be explained by the fact that in this survey 85% of study participants reported that they cleaned the filter on a daily basis, and therefore probably had a much higher contact with the filter than in the study in Bolivia. The average household size in the study in Bolivia was 5.4, smaller than in this study in Pakistan with 7.2; however, this alone cannot explain why 85% of the population in this study complained about the slow rate of water provision by the filters compared with only 8% in Bolivia. The turbidity of the source water here is again a likely explanation, as the study participants in

Bolivia did report that during the rainy season, source water was first settled before it was put in the top bucket.

Poor adherence to, and incorrect use of HWT is a frequently reported problem in HWT intervention studies, and they are blamed for HWT not achieving a significant health impact (Brown & Clasen 2012). How to improve adherence is still unclear, and whether the performance of the filters could have been improved if the planned follow-up visits had taken place is questionable. However, additional advice on how to maintain and clean the filters appropriately could have been provided and might have improved the life of the filters by preventing breakage. Additional visits do, however, come with an extra cost and are unlikely to be feasible, especially during emergencies when the population is more mobile.

Traditional water vessels in Pakistan are made of clay as they allow for natural evaporation and keep the water cool, which is important as temperatures can reach up to 45–50 °C in summer (Jensen *et al.* 2002). The Nerox™ filter had to be suspended from the roof in order to create head and gravity flow through the membrane filter, and with very little to no shade provided by the shacks and tents used by the IDPs, the water in the plastic bags could reach high temperatures. Over 80% of the study population saw this as a serious disadvantage of the filter. Solar disinfection has a similar problem, although the bottles used can be refrigerated, while the water bags used by the Nerox™ treatment method cannot.

Health impact and cost

There is an ongoing discussion regarding the relative importance of water quality as one of the multiple routes of diarrhoea transmission (Schmidt & Cairncross 2009, Clasen *et al.* 2009); however, it is beyond discussion that household water quality interventions will have an impact on health only if they are used continuously and correctly. It is estimated that as many as 50 million people in Pakistan rely on irrigation water for all domestic purposes including drinking, as groundwater is unfit for consumption as a result of high salinity (Ensink *et al.* 2002). Irrigation water is high in turbidity especially during the monsoon season, and the use of membrane and ceramic filters in these settings is unlikely to succeed as such filters easily clog, as was shown in this study. Traditionally, multiple 20-litre clay vessels are used by households in Pakistan to collect and store water. Especially during the monsoon season the vessels are used to settle water and so improve water quality; the use of alum as a flocculant is also common. These water treatment methods and products could have been distributed and promoted in the IDP at a fraction of the cost, and would have likely resulted in a higher adherence.

The IDP in this study were displaced within their own province and were used to drinking irrigation water. Research in the southern Punjab into the association between childhood diarrhoea and the use of irrigation water for domestic purposes found no association between drinking water quality and childhood diarrhoea, but did find a significant association between the amount of water used per household and diarrhoea, suggesting that hygiene was more important than water quality (Van Der Hoek *et al.* 2001).

CONCLUSIONS AND RECOMMENDATIONS

The Nerox™ filters are not a long-term, sustainable filter solution, but fulfilled some of the criteria for a rapid response filter during emergencies as they were easy to transport and distribute. The cost of the Nerox™ was twice that of the ceramic filter but this was not reflected in a significantly better performance, which makes it an expensive alternative.

The filters were well appreciated by the recipients but the performance and adherence of the filters was poor, likely as a result of the high turbidity of the original water, and possibly because of the high temperatures in Baluchistan. As a result the impact on health, especially diarrhoeal disease, would have been minimal.

Local alternatives to the imported Nerox™ and ceramic candle filters were available at much lower cost, which would likely have resulted in a higher uptake.

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