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Effects of a Tropical Cyclone on the Drinking-water Quality of a Remote Pacific Island

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The effect of a cyclone (Ami, January 2003) on drinking-water quality on the island of Vanua Levu, Fiji was investigated. Following the cyclone nearly three-quarters of the samples analysed did not conform to World Health Organisation (WHO) guideline values for safe drinking-water in terms of chlorine residual, total and faecal coliforms, and turbidity. Turbidity and total coliform levels significantly increased (up 56 and 62 per cent, respectively) from pre-cyclone levels, which was likely due to the large amounts of silt and debris entering water-supply sources during the cyclone. The utility found it difficult to maintain a reliable supply of treated water in the aftermath of the disaster. Communities were unaware they were drinking-water that had not been adequately treated. Circumstances permitted this cyclone to be used as a case study to assess whether a simple paper-strip water-quality test (the hydrogen sulphide, H_2S) kit could be distributed and used for community-based monitoring following such a disaster event to better protect public health. The H_2S test results correlated well with faecal and total coliform results as found in previous studies. A small percentage of samples (about 10 per cent) tested positive for faecal and total coliforms but did not test positive in the H_2S test. It was concluded that the H_2S test would be well suited to wider use, especially in the absence of water-quality monitoring capabilities for outer island groups as it is inexpensive and easy to use, thus enabling communities and community health workers with minimal training to test their own water supplies without outside assistance. The importance of public education before and after natural disasters is also discussed.

Keywords: Water quality, disaster events, tropical cyclone, coliform indicators, contamination, hydrogen-sulphide test, remote island communities.

Introduction and aims

Potable water on many small tropical islands is a scarce and vulnerable resource, which is often susceptible to contamination from poorly installed sanitation facilities (Falkland, 1999). The sudden occurrence of a natural disaster, such as an earthquake, volcanic eruption, tidal wave or cyclone, may result in increased contamination (for

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example, from salt, silt and pathogens) and disruption of distribution and treatment. Limited documented water-borne (for example, typhoid fever) disease information from the Pacific Islands indicates that cyclones create a much higher health risk than expected, which may persist for a long period of time following an event (Finau, 1983; Finau et al., 1986; Samoa Ministry of Health, 1993). Low-lying islands and atolls are likely to be the most seriously affected as they often rely on water from shallow and fragile ground-water lenses (Dupon, 1986).

Often the financial and technical capacity of remote island communities to deal with natural disasters is limited, resulting in a dependency upon assistance from other locations that may be miles away across open water. It may take months for water and sanitation services to be restored, and for vector- and pest-control activities to be carried out. Following a disaster, it is important to provide affected communities with an adequate supply of good-quality water. Although unsafe water can be made safe by boiling or chemical treatment, this is not often practised and many people rely on the misconception that publicly supplied tap water is safe to drink. It is very important that sustained and appropriate public-education activities are carried out in order to limit the effects of cyclones on public health. Ideally, public education on cyclone preparedness should take place before a cyclone strikes, preferably in the period immediately preceding the cyclone season and continue throughout the cyclone season even if no cyclones occur. Good cyclone forecasting and tracking ability coupled with quick response by local disaster management and health authorities is also important. If both of these factors are enhanced, it will enable people to be better prepared, such as stocking up on bottled water.

The Pacific islands are continually subject to the effects of natural disasters, with an average of eight tropical cyclones per year in the south-west Pacific during the period 1920–94 (Radford et al., 1996). From 12–15 January 2003, Cyclone Ami hit the Fiji Island group (see Figure 1) and had a devastating effect on the islands of Vanua Levu, Taveuni and the eastern islands of the Lau group. Average windspeeds were between 80 and 110 knots and very high rainfall was recorded (300–400 mm/day). In Vanua Levu, at least 14 lives were lost in a large flood that swept through a settlement in the middle of the night. Many homes, bridges, roads and plantations were destroyed. Labasa, the main town on this island was under three metres of water at the peak of the flooding. The supply of piped water in some areas was disrupted due to infrastructure damage and on some supplies, treatment was not maintained. Approximately one month following the cyclone, rumours led to concerns about the quality of drinking-water, particularly on the island of Vanua Levu. Health authorities were concerned that outbreaks of typhoid fever and vector-borne diseases such as dengue fever would occur.

The main aim of the current study was to evaluate changes in drinking-water quality on the island of Vanua Levu following the cyclone and to acquire knowledge that can be used to mitigate the effects of future disasters. Published data from the Pacific Islands on water quality following cyclones were not available, although studies of hurricanes in other locations have shown significant negative impacts (Winstanley and Changnon, 1999). Unfortunately there was no water-quality monitoring capability based on Vanua Levu so there were inherent problems with sample collection, preservation and transport back to the central laboratory located in the town of Labasa. Monitoring, when conducted, is sporadic and is done by the same agency responsible for managing the publicly-owned water utility (Public Works Department) so potential conflicts of interest occur.

Figure 1 The location of Vanua Levu in the Fiji Island group and the path and satellite image of Cyclone Ami (*Source:* Fiji Metereological Service)

In order to conduct bacteriological testing of water, incubators and specialised training and knowledge are usually required. Although portable battery-powered incubators are available which are suitable for outer island use, these are generally of limited capacity that allow only a small number of samples to be analysed. Considering these problems, it was thought that the simple low-cost test for faecal pollution in water, called the hydrogen-sulphide (H_2S) paper-strip test, developed by Manja et al. (1982), might be a good alternative to trial. The H_2S test is a presence/absence test which changes colour (turns black) when H_2S-producing bacteria of faecal origin (for example, Clostridia sp., Salmonella sp., Proteus sp.) are present. These tests have also been shown to correlate well with conventional (total and faecal coliforms) tests (Manja et al., 1982; Dutka, 1990; Castillo et al., 1994; Martins et al., 1997). As noted in a multi-country comparative study summarised by Dutka (1990), this test is 'an ideal tool for testing rural and isolated drinking water supplies'. The major advantages of the H_2S test are that it is cheap to manufacture, simple to use, does not require any sophisticated equipment (an incubator) and can be easily understood by people with little or no science background. It is, therefore, an ideal tool to demonstrate the effect of household-based water treatment (boiling/chlorination). In the current study, field trials were conducted of the H_2S kit and compared results versus those obtained using conventional methods for the enumeration of total and faecal coliforms. The goal was to assess the potential for its use to protect the health of outer-island communities following similar disaster situations.

Materials and methods

Sampling sites and methods

Sampling was undertaken approximately four weeks after Cyclone Ami subsided, when the potential for a disease outbreak was noted by health authorities. Samples were taken from a number of sites around the island of Vanua Levu, in the northern Fiji Island group (see Figure 1). The majority of samples were taken from the publicly owned supplies, although several private boreholes were sampled. For the publicly-owned supplies, samples were taken at both the water sources (river intakes and boreholes) and also at reticulation endpoints. Before samples were taken, all standpipe taps were flamed for approximately 30 seconds to destroy any bacterial contamination present on the mouth of the tap. For the analysis of faecal and total coliforms, a 500ml sample was collected in a sterile glass bottle, stored in ice in a cooler and returned to a basic laboratory in the town of Labasa. The time between sampling and further processing of the samples was less than eight hours.

Analysis methods

Some of the water-quality parameters (pH, turbidity, chlorine-residual) were analysed at each sampling site using standard methods (Eaton et al., 1995). Upon return to the laboratory, the membrane-filtration technique was used to enumerate total and faecal coliforms. A measured volume (100mL) of each sample was filtered on to a sterile membrane (Millipore 47mm), placed on to growth media and incubated for approximately 24 hours at recommended temperatures (Eaton et al., 1995). The media used was HACH M-ColiBlue24 which can enumerate both faecal and total coliforms on the same plate.

H_2S test kits were made following the method described by Manja et al. (1982). The media consisted of the following chemicals: 40g of bacteriological peptone, 3g of di-potassium hydrogen phosphate, 2g of sodium thiosulphate, 1.5g of ferric ammonium citrate, 2ml of liquid detergent and 100mL of de-ionised water. This provided enough media for about 200 tests. The strips were prepared by pipetting 2ml of the media on to the pads used to absorb broth used in membrane filtration (47mm, Gelman) and were then dried at 50 °C in an oven. The dried pads were cut into quarters to make four H_2S strips each containing 0.5ml of the media. Each strip was then placed in a clear plastic tube calibrated to 10ml volume, and sterilised by UV light in a biological safety cabinet for at least 30 minutes. Alternatively, if pyrex bottles are used, a hot air oven or an autoclave could be used for sterilisation. As long as the media impregnated paper strips are kept dry and in the dark, they can be stored without refrigeration indefinitely.

At the time of sampling, 10ml water samples were collected directly into the H_2S tubes, the lid tightly capped and the sample left in the dark at ambient temperature

(25–30 °C) for 36 hours. After about 12 hours of incubation-time, and each 12 hours thereafter, an observation was made to determine if a colour change had taken place. A change to black indicates a positive reaction and the production of hydrogen sulphide, which typically indicates the presence of bacteria of faecal origin (Manja et al., 1982; WHO, 2002a). The speed and intensity of the colour change is reflects the density of sulphide-reducing bacteria present in the sample. The date and time of each observation were recorded as follows: '–' means no change; '+' means slight change, the paper strip or water has turned grey; '++' means the paper strip is partially black; '+++' means the strip and the water sample itself is noticeably black. The time-scale of the colour change can also be interpreted in terms of risk to public health. A colour change to black in less than 12 hours indicates a potentially high-risk situation, a change on day two is associated with moderate risk and on day three, slight risk. At the end of the field study, the samples were returned to a laboratory in Suva, the capital, for analysis to determine the presence of Clostridium perfringens, an H_2S producer and an alternative indicator of faecal pollution. Although it was possible to test for its presence a week after sampling due to it being a spore-forming anaerobic bacteria, capable of surviving in the H_2S media.

Approximately six weeks before the cyclone (26 November 2002), the Public Works Department tested water quality at a number of the same sites as the current study. These data were analysed to determine the effects of the cyclone on water quality before and after the event. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) to analyse pre- and post-cyclone water-quality differences. Some samples had a coliform count that was too high to count (TNTC) which did not enable numerical comparisons of the effect of the cyclone to be made, even though in certain cases effects were obvious. Therefore, these samples were ascribed a value of 500 colonies per 100ml in order to be able to make paired sample T-test calculations to determine the effect of the cyclone.

Results

Water-quality results

The water-quality data from samples taken after Cyclone Ami at various water supplies and reticulation endpoints in Vanua Levu are shown in Table 1. Several samples exceeded WHO guidelines for safe drinking-water for various water-quality parameters. Over 70 per cent of the samples analysed for residual-chlorine level, over 70 per cent for total faecal coliforms, over 65 per cent for faecal coliforms and 17 per cent for turbidity were outside WHO guidelines, which are <0.5mg Cl/L, >0 coliforms/faecal coliforms per 100mL and >5 NTU, respectively (WHO, 1996). Several water supplies (Vunicuicui, Nasarava, Nasasala, Tuganikula, Nabekavu) were contaminated with coliform and faecal coliform bacteria (see Table 1). For samples which were above the WHO recommended chlorine level (> 0.5mg/L), the great majority (> 95 per cent) had no total and faecal coliform bacteria and tested negative in the H_2S tests.

The cyclone had a negative impact on water quality: samples taken after the cyclone showed on average greater than 50 per cent more turbidity; 60 per cent more coliform bacteria; and more than 40 per cent less chlorine than samples taken at the

Table 1 List of sample locations, water-supply types and water-quality data

Sample site, date and type	*pH*	*Temp. (°C)*	*Free Cl (mg/L)*	*Turbidity (NTU)*	*H_2S*	*Coliforms (col./100mL)*	*Faecal coliforms (col./100mL)*
Labasa Town							
Nakama borehole							
5/15 borehole	7.2	29.8	0	1.8	yes	62	21
Nasealavu stream supply							
5/15 stream	7.4	27.8	0	1.1	yes	247	111
Labasa Town: market							
2/20 endpoint	6.9	25.6	0.76	3.7	no	1	0
Labasa Town: hospital							
2/20 endpoint	7.1	25.8	0.46	2.2	no	0	0
Bulileka village							
2/20 endpoint	7.3	26.8	0.58	2.5	no	0	0
Labasa water depot							
2/20 endpoint	7.3	27.2	0.74	2.0	no	1	0
Labasa Town service stn.							
2/20 endpoint	7.2	22.1	0.6	3.0	no	0	0
Vunika							
Vunika borehole							
2/20 borehole	7.4	28.1	0	3.6	yes	8	1
Vunika borehole							
5/13 borehole	6.4	29.4	0	9.8	yes	0	0
Vunika store							
2/20 endpoint	7.1	29.6	0	4.8	yes	6	1
Vuo village							
2/20 endpoint	7.1	30.0	0	2.8	no	4	0
Mani Lal Shoppe							
5/13 endpoint	6.9	39.1	1.7	4.4	no	0	0
Vuo village							
5/13 endpoint	7.1	29.6	0	2.8	no	0	0
Vunicuicui							
Vunicuicui borehole							
5/13 borehole	6.9	29.6	0	1.4	no	21	10
Korowiri village							
2/20 endpoint	7.7	29.8	0	1.8	yes	TNTC	0
5/13 endpoint	7.4	29.4	0	1.6	yes	76	11
Vunicuicui Ram Dutt store							
2/20 endpoint	7.2	29.9	0	1.8	yes	TNTC	0
Vunicuicui school							
2/20 endpoint	7.1	30.5	0	1.1	yes	TNTC	1
Nasarava							
Nasarava water supply							
5/15 stream	7.4	29.5	0	2.0	yes	300	170
Naduna house supply							
2/20 endpoint	7.5	31.2	0.86	2.7	no	16	1
Nakama village							
2/20 endpoint	7.4	32.0	0	6.5	yes	TNTC	4
Ram Kisun shoppe							
2/20 endpoint	7.3	30.1	0	3.8	yes	62	2
Nasalasala							
Nasalasala water supply							
5/15 stream	7.3	29.4	0	1.7	yes	400	141
Reddy private residence							

2/20 endpoint	7.5	31.3	0	2.9	yes	40	10
5/15 endpoint	7.4	30.0	0	2.0	yes	TNTC	42
Prasad residence							
2/20 endpoint	n.d.	n.d.	0	3.3	yes	TNTC	8
Bua							
Bua borehole							
2/20 borehole	7.6	27.5	0	1.0	no	32	6
Vunivau school							
2/20 endpoint	7.4	27.7	0	0.4	yes	19	8
Nabouwalu							
Nabouwalu stream							
17/6 stream			0	2.5	n.d.	450	194
Namau residence							
2/21 endpoint	7.3	28.8	0.16	8.0	no	0	0
Nabouwalu market							
2/21 endpoint	7.3	28.4	0.08	1.5	no	0	0
Nabouwalu PWD depot							
2/21 endpoint	7.3	28.9	0.02	1.5	no	0	0
Nabouwalu Hospital							
2/21 endpoint	7.6	29.8	0.92	1.5	no	0	0
Savusavu							
Savusavu stream							
18/6 stream	n.d.	n.d.	0	1.8	n.d.	230	104
Vishnu depot							
2/21 endpoint	6.2	31.3	0	n.d.	yes	48	23
Savusavu hospital							
2/21 endpoint	6.5	32.2	1.66	2.0	no	0	0
PWD water supply depot							
2/21 endpoint	6.6	31.7	0	1.3	yes	0	0
Savusavu market							
2/21 endpoint	6.6	31.5	0.86	2.1	no	0	0
Savusavu Hotsprings hotel							
2/21 endpoint	6.7	30.9	1.04	3.0	no	0	0
Savusavu airport							
2/21 endpoint	6.5	30.2	0.66	2.2	no	0	0
Tuganikula							
Tuganikula water supply							
5/13 stream	7.2	29.5	0	2.7	no	TNTC	6
Abdul residence							
2/22 endpoint	7.9	29.2	0	3.7	yes	29	15
Wainikoro residence							
2/22 endpoint	7.1	28.4	0	2.6	yes	21	13
Pyare shop							
2/22 endpoint	7.9	29.5	0	2.2	yes	8	3
5/13 endpoint	6.8	29.9	0	2.8	yes	TNTC	7
Durga shop							
2/22 endpoint	7.3	30.4	0	n.d.	yes	31	20
5/13 endpoint	7.0	29.5	0	2.1	yes	49	5
Nabekavu							
Nabekavu borehole 1							
5/15 borehole	7.0	30.0	0	3.0	yes	24	16
Nabekavu borehole 2							
2/22 borehole	7.0	30.0	0	4.2	yes	41	9
5/15 borehole	7.0	29.1	0	1.8	yes	5	3
Nabekavu reservoir							

2/22 endpoint	7.1	29.8	0	8.5	yes	20	11
Wailevu shop							
2/22 endpoint	7.0	29.9	0	6.6	yes	13	8
5/15 endpoint	7.5	30.5	0.68	1.4	no	13	n.d.
Waiqele school							
2/22 endpoint	7.0	29.8	0	3.9	yes	15	7
Waiqele residence							
5/15 endpoint	7.3	29.6	1.2	1.4	no	0	0
Seaqaqa							
Seaqaqa water supply							
6/18 river	n.d.	n.d.	0	2.9	n.d.	200	106
Seaqaqa hospital							
2/22 endpoint	7.8	28.7	0.4	15.0	no	8	2
Seaqaqa school							
2/23 endpoint	7.0	30.2	0.32	50.0	no	19	0
Seaqaqa water plant							
2/24 endpoint	6.9	30.4	0.34	3.0	no	0	0

Note: n.d. = not determined, no data available for this sample.

same sites before the cyclone (see Table 2). The increases in turbidity and coliform bacteria were found to be statistically significant in the paired sample t-tests (see Table 2). No significant difference was observed in faecal coliform levels.

Evaluation of the hydrogen sulphide (H_2S) test

The H_2S test turned positive (black) for most samples that had faecal and total coliform levels above the respective WHO guidelines. Only about 11 per cent and 8 per cent of the samples that contained faecal and total coliform bacteria, respectively, did not test positive in the H_2S test. About 2 per cent and 6 per cent of the samples that tested positive in the H_2S test did not have any total and faecal coliform bacteria, respectively, present.

During the second visit to Vanua Levu, several of the positive H_2S tests were re-tested for the presence of the spore-forming anaerobic bacteria, Clostridium perfringens, which is a strong H_2S producer and an indicator of faecal pollution. The results showed a relationship to the speed of H_2S development as shown in Table 3. Nearly 50 per cent of the samples returned positive C. perfringens results, which indicated faecal contamination had entered into water supplies or the reticulation system. About 25 per cent of samples that tested positive with the H_2S test had undetectable levels of C. perfringens. However, these were generally the samples where the H_2S test was slow to turn black, indicating that few H_2S producing micro-organisms were present when the sample was collected.

Public-education activities

Despite the concern over the risk to public health following the cyclone, very limited public-education activities were conducted by local authorities. However, the Red Cross distributed chlorine tablets from their office in the town of Labasa. In the current study, members distributed public-awareness pamphlets in the local languages on how to make water safe to hospitals, community health centres, schools and villages.

Unfortunately, the impact of the education material delivered in the current study was not evaluated due to lack of time and relevant expertise.

Discussion

Cyclone Ami greatly affected water quality on the island of Vanua Levu. The negative effects were most likely due to soil, bacteria and other debris washing into rivers and streams and entering groundwater supplies. The lack of adequate treatment meant that this contamination was transferred through the reticulation system. This posed a great risk for human health in these areas as these supplies were used for drinking purposes without further treatment. Up-to-date health statistics from the Vanua Levu area were unavailable but health statistics from 1990–93 in Western Samoa showed that two typhoid outbreaks occurred in the months following the cyclones Ofa and Val (Samoa Ministry of Health, 1993).

The results of the current study highlight the importance of maintaining chlorination when source waters are contaminated with bacteria, and even increasing chlorine levels during natural disasters when water quality is threatened. Only a few chlorinated supplies had coliforms present and these may have been due to recent pollution, and/or high turbidity levels. A number of the water supplies are chlorinated during normal operations but at the time of sampling it was noted that several were not being dosed with chlorine or chlorine levels had significantly decayed in the distribution network, which resulted in ineffective disinfection. The reason for the lack of chlorine dosing is not clear but it appears to be largely from a lack of will power on the part of the treatment plant operators. Treatment has since been restored or introduced at a number of supplies and several boreholes have been disinfected with chlorine (by a drip-feed system) following notification of the results reported in the current study (Public Works Department, personal communication).

Interestingly, there was not a significant difference in the levels of faecal coliforms in paired samples taken before and after the cyclone although many of the pre-cyclone levels already greatly exceeded WHO guidelines (see Table 2). Hence although a disease risk already existed, the cyclone may not have increased this risk based on the faecal coliform indicator results. It should, however, also be noted that faecal (thermotolerant) and total coliform bacteria may not be ideal indicators of sanitary quality for tropical waters. Some species of these groups have been found to occur naturally in a variety of ecological niches (for example, aquatic slime, soil, vegetation, wild animals) and they can multiply at the temperatures found in tropical

Table 2 Changes in water-quality parameters for samples taken at the same site pre- and post-cyclone

	Free Cl (mg/L)	*Turbidity (NTU)*	*Total coliforms (CFU/100mL)*	*Faecal coliforms (CFU/100mL)*
Number of paired samples	48	53	50	49
Pre-cyclone average	0.42	1.8	40	56
Post-cyclone average	0.23	4.1	106	46
Average change	45%	+56% *	+62%**	–17%

'*' and '**' denote significant differences at the $p<0.05$ and $p<0.01$ level, respectively, for the change in water quality of paired samples pre- and post-cyclone.

environments (Dutka, 1973; WHO, 1996; Fujioka and Shizumura, 1985). Yet their presence in waters in warm climates should not be ignored, as the basic assumption that pathogens may be present and that treatment has been inadequate still holds.

In the current study, the H_2S test showed good agreement with the conventional faecal and total coliform tests, particularly considering the difficulties in conducting tests in the remote areas of Vanua Levu. Hence we believe that the test could be more widely used to routinely screen water quality on outer islands and rural areas. For a small number of samples, a positive total and/or faecal coliform result showed a negative in the H_2S testing yielding what is termed 'false-negative' results. Similar disparities have been observed in other studies (see WHO, 2002a for a summary) and are not unexpected as there are slight differences between the respective tests. The sample volume we used in the H_2S test (10ml) was less than for the coliform-type indicators (100ml), so the statistical probability of finding bacteria will be lower. Also there is an increased risk of introducing bacterial contamination when collecting and examining samples for faecal and total coliforms, due to the increased number of handling and filtration procedures, as compared to the H_2S test. This is particularly relevant when using the membrane-filtration method in difficult non-laboratory conditions prevalent on outer islands.

Upon closer examination of the results, many of the 'false-negative' samples found had quite low levels of faecal and total coliform bacteria (for example, see Labasa water-depot sample results in Table 1). Therefore, the belief is that in many cases people drinking-water that gave 'false-negative' results in the H_2S tests would not necessarily be exposed to an increased disease risk. Likewise a small number of samples that tested positive in the H_2S testing tested negative for total and/or faecal

Table 3 *Clostridium perfringens* presence in relation to H_2S development in samples taken after the cyclone. '+++' indicates dark blackening of the H_2S test solution and paper strip, '++' indicates moderate blackening and '+' light blackening

Sample site		*H_2S development*		*C. perfringens*
	Day 1	*Day 2*	*Day 3*	*(yes/no)*
Taganikula water supply	+++	+++	+++	Yes
Vunika borehole	+++	+++	+++	Yes
Momi Lal shoppe				No
Vuo village	+++	+++	+++	Yes
Korowiri village				No
Vunicuicui borehole				No
Wailevu shop	+++	+++	+++	Yes
Nabekavu borehole 1				No
Nabekavu borehole 2				No
Waiqele residence		+	+++	No
Nasarava water supply			+++	No
Nasalasala water supply				No
Reddy residence	+	++	++	Yes
Nakama borehole	+	+	+	No
Nasealavu water supply			++	Yes
Taganikula water supply			+	No
Vunika borehole		++	++	Yes

coliforms result, which is termed a 'false positive'. This is likely due to the fact that some H_2S-reducing bacteria (for example, Clostridium sp.) persist in the environment longer than coliform bacteria. (WHO, 2002a). It could possibly be due to naturally occurring sulphide reducing bacteria being present, but the conditions needed for these bacteria to thrive are anaerobic waters with high organic matter and sulphate content.

None of the waters sampled fitted this description so we consider these results are unlikely to be false-positives in the sense of a natural H_2S producer being present. In any case, a false positive result is less likely to lead to a risk of disease because it would result in the suspect water either not being used, disinfected or subject to additional testing. However, further research in the drinking-waters of the Pacific Islands, would be beneficial to confirm the link between positive H_2S test results and the presence of faecal contamination and pathogens.

A key benefit of the H_2S test compared to other water-quality tests is that it enables communities and community health workers with minimum training to safely test their own water supplies. A positive result in a H_2S test is visual (a black colour change occurs) and therefore simple for people to understand and realise when bacteria levels in their drinking-water are high. Unlike conventional membrane-filtration tests, the H_2S test is very simple to use, requires no filtration and incubation is done at room temperature (24–36 °C) so no equipment is required. Hence even if power supplies are not in operation (as is likely after a cyclone), water-quality results can still be obtained. Other significant advantages of the H_2S test are that it is very low in cost (about US$0.05/test) and little laboratory equipment is required for manufacture, other than a simple balance to weigh the media, pipettes, and a method of sterilising the kits (hot oven, autoclave, UV light). The above factors mean that H_2S kits can easily be produced in countries where laboratories are poorly equipped, or distributed by a regional organisation, when needed. Although we did not distribute H_2S test kits to local communities in the current study, we believe that they could be used to protect public health following subsequent natural disasters. For example, following a cyclone, thousands of kits could be locally manufactured and distributed in a short time period (few days) to individual households by community health workers along with printed material on their use. As most water sources on outer islands are localised small community or individual sources, time and resources could be focused on distribution of the kits to the maximum number of people. This would mean that many more drinking-water supplies are tested compared to if conventional methods were used by a water or health agency. This should enable better protection of human health following disasters.

With enough explanation of the H_2S test, there should be no need to go back and tell households that their water is contaminated as they can interpret the test themselves. If results indicate high risk, households would be instructed to treat their water to make it bacteriologically safe before drinking. Various household disinfection techniques could be recommended such as boiling, adding a few drops of chlorine bleach (4 drops per litre), and/or putting the water in a clear plastic bottle and exposing it to full sunlight for a minimum of four hours (for example, 10.00 a.m.–2.00 p.m.). Two H_2S tubes could be distributed to each household, with instructions to fill one with untreated water and the other with water that has been treated. After the 2–3 days of incubation, no colour change should occur in the treated sample, which clearly shows that the organisms that caused the untreated sample to turn black have been killed. Communities would also have evidence to alert the relevant authorities that water which is supposedly treated is still contaminated, as was the case in Vanua Levu.

The risk of contracting water-borne illnesses could have been lowered in the current disaster situation by better public-awareness activities, and improved post-disaster management by local authorities and water-supply companies. Health authorities should have conducted awareness campaigns on radio and visited affected communities. However, they may have been unaware of the actual risk due to the water-supply company not informing them or the public of the breakdown in treatment efficiency. Chlorine tablets and printed information (in local languages and picture-book form) on how to treat water should continue to be distributed by relief agencies. In such tropical areas, the liquid content of green coconuts can also be publicised as a safe drinking-water source during emergencies. The World Health Organisation has published a good resource book on environmental health following disasters, which provides ideal information for relief and community health workers (WHO, 2002b).

Conclusions

Tropical cyclone Ami resulted in a significant deterioration of water quality on the island of Vanua Levu in the Fiji Island group. Soil and bacteria contamination entered into water sources and poor water treatment led to this contamination being transferred through the reticulation system. This then created a public health risk. The simple H_2S test was evaluated and showed a good correlation with results from conventional faecal and total coliform analyses. The H_2S test would be ideal for community-based use following natural disasters, particularly in areas such as remote islands where conventional water-quality monitoring is difficult. Better co-ordination between, and response from, local water and health authorities would also have been beneficial.

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