Wat. Sci. Tech. Vol. 27, No. 3-4, pp. 145–150, 1993.
Printed in Great Britain.

0273–1223/93 $24·00

THE APPLICATION OF RISK ASSESSMENT TECHNIQUES TO MICROBIAL MONITORING DATA: A SOUTH AFRICAN PERSPECTIVE

N. Rodda*, A. Amory** and R. Kfir*

** Division of Water Technology, CSIR, P.O. Box 395, Pretoria 0001, South Africa*
*** Biology Department, University of Natal, King George V Avenue, Durban 4001, South Africa*

ABSTRACT

The feasibility of applying microbial risk assessment techniques in South Africa was evaluated by assessing risks associated with enteric viruses in raw and treated drinking water. Maximum daily risks associated with treated drinking water were in the range $2x10^{-2}$ - $7x10^{-1}$. If levels of viruses in treated drinking water were approximated from those in raw water by assuming reductions during treatment of 4 log, 5 log and 6 log, maximum daily risk estimates were $4x10^{-2}$ - $4x10^{-1}$, $5x10^{-3}$ - $1x10^{-1}$ and $5x10^{-4}$ - $1x10^{-2}$, respectively. A number of complicating factors were identified. Detection limits were high and volumes of water monitored were low. There was no information on viral pathogen removal during treatment. Application of risk assessment techniques within these limitations clearly showed the volume of water monitored to be the most important factor limiting detection of low risk levels. The sampling and concentration of large water volumes (at least 100ℓ) for microbial analysis was identified as an urgent need.

KEYWORDS

Health risk assessment, microbial monitoring, enteric viruses, echovirus, poliovirus, South Africa.

INTRODUCTION

Risk assessment aims to provide a quantitative estimate of the probability of illness associated with environmental exposures. In the absence of suitable epidemiological data, it holds potential as a useful tool for the formulation of water quality guidelines. Risk assessment techniques have been used to a considerable extent in the development of chemical guidelines (Cotruvo, 1987; US EPA, 1987) and have been proposed for the development of microbial water quality guidelines (Rose and Gerba, 1991).

The United States Environmental Protection Agency (EPA) has proposed a microbial drinking water guideline based on risk. It requires that water treatment reduces levels of *Giardia* and viruses by 3 log and 4 log respectively to achieve a yearly risk of infection not greater than 10^{-4} (Federal Register, 1989).

The application of microbial risk assessment in the development of water quality guidelines would be of considerable benefit in South Africa. Risk-based guidelines would permit guidelines to be derived from community-based perceptions of acceptable risk and from cost-benefit considerations. However, a number of factors complicate the use of microbial risk assessment in the South African context. Although currently used viral detection methods have high recoveries (approaching 90%), the detection limits are high and volumes of water analyzed are low. There is relatively little information on treatment efficacy, particularly with respect to pathogen removal, and exposure data are limited.

This study assesses the feasibility of applying microbial risk assessment techniques in South Africa within the limitations described above. The effect of these factors on risk detection and calculation was evaluated. Specifically, risks associated with enteric viruses in raw and treated drinking water were estimated.

RISK MODEL

The beta-distributed infectivity probability model was selected since review of probability models of infection indicated that this model provided the best description of viral infection (Haas, 1983; Gerba and Haas, 1988). The model, and representative parameter values for a number of enteric viruses, are shown in Fig. 1 and Table 1.

$$P = 1 - (1 + N/\beta)^{-\alpha}$$

P = probability of infection from a single exposure (daily risk of infection)
N = number of organisms ingested per exposure
α, β = parameters characterising the host-virus interaction

Fig. 1. Beta-distributed infectivity probability model

TABLE 1 Representative values of parameters α, β for beta-distributed risk model

	Echovirus 12	Poliovirus 1	Poliovirus 3
α	1.3	15	0.5
β	75	1 000	1.14

The model shown in Fig. 1 estimates daily risks. Longer term risk can be determined from daily risk values, calculated using a measure of central tendency over the period of interest, usually the geometric mean (Fig. 2).

A number of assumptions, previously described by Rose and Gerba (1991), were employed. Occurrence of viruses in water was assumed to be governed by a Poisson distribution. All members of the exposed population were considered to be equally susceptible to a single exposure, and an adult water consumption of 2ℓ per day was assumed (Rose and Gerba, 1991). In addition, a number of assumptions may be employed in the use of data sets incorporating non-detect results. In this study, the effects of substituting non-detect results with half the detection limit and with zero were compared.

$$Px = 1 - (1 - P(N))^{x}$$

Px = probability (risk) of one or more infections over period x
x = number of days of exposure
P(N) = daily risk, using measure of central tendency for N (usually geometric mean)
N = measure of organisms ingested on daily basis over period x (usually geometric mean)

Fig. 2. Calculation of risk over longer exposure periods

CASE DESCRIPTION

The raw water data used in this study represent one of three sources which contribute to the drinking water supply of the most densely populated region of South Africa. Water from the three sources is mixed and treated by high pH lime coagulation and breakpoint chlorination. Water from the treatment plant supplied by the monitored source serves approximately 2.3 million people.

The extent of enteric virus removal during treatment was not known. Removal of faecal coliforms was approximately 6 log, and that of bacteriophages was between 5 log and 6 log (Rand Water Board, pers. comm.). This may be compared with the EPA recommended virus removal of 4 log (Federal Register, 1989).

Sample volumes of 10ℓ of raw and treated water were concentrated by ultrafiltration and analyzed by cell culture methods. Enteric viruses were reported as the most probable number (MPN) 50% tissue culture infective dose ($TCID_{50}$) per 10ℓ (Grabow and Nupen, 1981). The detection limit was 63 MPN $TCID_{50}$ per 10ℓ. Monitoring data for raw and treated water for the period April 1981 to March 1991 were evaluated.

Detection methods were based on observation of cytopathogenic effects in cell culture and allowed for distinction of enteroviruses and reoviruses. Risk model parameter values were available for the enteroviruses echovirus 12, poliovirus 1 and poliovirus 3 (Table 1; Haas, 1983). No parameter values were available for reoviruses. Hence only data on enteroviruses were considered, and echovirus 12, poliovirus 1 and poliovirus 3 were considered as representative enteric viruses in risk calculations.

RESULTS AND DISCUSSION

Evaluation of geometric mean virus levels in raw water over the monitoring period, with data aggregated by month, showed that the highest enteric virus levels were recorded in July (Fig. 3). This corresponds to midwinter in South Africa, during which the raw water source is typically dominated by low flow conditions. It is also the period during which the highest probability exists that this raw water source contributes a significant proportion of the raw water supply for treatment. Information relating to expected health risks associated with the water before and after treatment can therefore assist in the management of water treatment and supply, and in the protection of public health. No enteric viruses were detected in treated drinking water monitored over the same period. This is obviously desirable in terms of water supply, but complicates direct estimation of risk associated with drinking water.

Daily risks associated with treated drinking water were estimated at the minimum measurable limit, *i.e.* the detection limit, and at one non-detect surrogate value, *viz.* half the detection limit, for all 3 representative enteric viruses (Table 2). Based on analysis of treated drinking water, it may be concluded that daily risks of enteric virus infection did not exceed $2x10^{-1}$ to $7x10^{-1}$, if echovirus 12 and polioviruses 1 and 3 were considered as representative enteric viruses. This corresponds to the minimum measurable risk. If it is assumed that non-detect results can be safely substituted by half the detection limit, then the maximum daily risk probably did not exceed $9x10^{-2}$ to $6x10^{-1}$. This is considerably higher than the mean yearly risk of 10^{-4} recommended by the EPA. Detection of low risk levels in drinking water was hampered by small sample volumes and a high detection limit.

In an attempt to circumvent some of the difficulties associated with non-detect results in drinking water, virus levels in treated water were estimated from raw water levels. Enteric virus removals of 4 log, 5 log and 6 log were assumed on the basis of approximate bacteriophage removal, and EPA recommended virus removal. This allowed alternative estimates to be developed of risks associated with drinking water. Expected values of maximum daily risk were based on distributions of monitoring data, aggregated by month. Mean yearly risks were based on distributions of monthly

arithmetic means and monthly geometric means. Non-detect results were substituted by half the detection limit or zero (Table 3; 1 MPN $TCID_{50}/10\ell$ was used instead of zero for the calculation of geometric means).

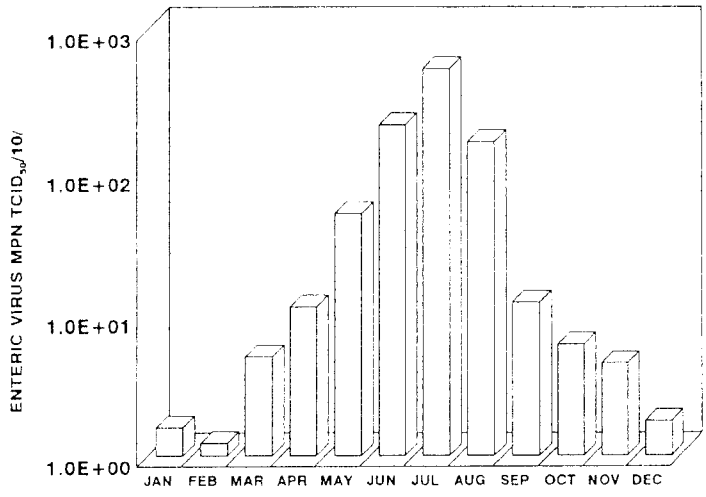

Fig. 3. Geometric mean virus levels in raw water data for the period April 1981 - March 1991, aggregated by month

TABLE 2 Daily Risks of Enteric Virus Infection Associated with Treated drinking Water

	Echovirus 12	Poliovirus 1	Poliovirus 3
At detection limit (63 MPN $TCID_{50}/10\ell$)	2×10^{-1}	2×10^{-1}	7×10^{-1}
At half detection limit (31.5 MPN $TCID_{50}/10\ell$)	1×10^{-1}	9×10^{-2}	6×10^{-1}

If a 4 log reduction during treatment was assumed, expected maximum daily risks associated with drinking water were estimated in the range $4x10^{-2}$ to $4x10^{-1}$, considering echovirus 12 and polioviruses 1 and 3 as representative enteric viruses. If a 5 log reduction was assumed, expected maximum daily risk values were in the range $5x10^{-3}$ to $1x10^{-1}$. An assumed 6 log reduction during treatment yielded maximum daily risk estimates in the range $5x10^{-4}$ to $1x10^{-2}$. Mean yearly risks were similar to maximum daily risks. Risk estimates for poliovirus 3 were noticeably higher, overall, than those for echovirus 12 and poliovirus 1.

Risk calculations were relatively insensitive to the treatment of non-detect results, since substitution of non-detects with either half the detection limit or zero yielded the same or similar risk estimates. This indicates that the high detection limit of techniques used in South Africa does not affect risk estimates significantly.

Maximum estimated risks were considerably higher than the EPA recommended yearly risk of 10^{-4}. However, daily risks estimated at lower virus levels were markedly reduced, with the lowest estimates of the order of 10^{-7}. Detection of low risks was hindered by the small sample volumes analyzed. Expected values of maximum daily risks calculated assuming 4 - 6 log reductions in enteric virus levels relative to raw water (Table 3) were lower than daily risks estimated for treated water (Table 2). This was to be expected since the latter risk estimates were dependent on sample volumes and assumptions regarding non-detect results.

TABLE 3 : Daily and Yearly Risk Estmates for Echovirus 12, Poliovirus 1 and Poliovirus 3

Assumed removal during treatment	Expected value of risk		
	Maxmum daily risk	Mean yearly risk (geometric mean)	Mean yearly risk (arithmetic mean)
A. Echovirus 12			
Non-detect value: 13.5 MPN $TCID_{50}/10\ell$			
4 log	5×10^{-2}	6×10^{-2}	2×10^{-1}
5 log	5×10^{-3}	6×10^{-3}	3×10^{-2}
6 log	5×10^{-4}	6×10^{-4}	3×10^{-3}
Non-detect value: 0 MPN $TCID_{50}/10\ell$			
4 log	5×10^{-2}	3×10^{-2}	2×10^{-1}
5 log	5×10^{-3}	3×10^{-3}	3×10^{-2}
6 log	5×10^{-4}	3×10^{-4}	3×10^{-3}
B. Poliovirus 1			
Non-detect value: 13.5 MPN $TCID_{50}/10\ell$			
4 log	4×10^{-2}	5×10^{-2}	2×10^{-1}
5 log	5×10^{-3}	5×10^{-3}	3×10^{-2}
6 log	5×10^{-4}	5×10^{-4}	3×10^{-3}
Non-detect value: 0 MPN $TCID_{50}/10\ell$			
4 log	4×10^{-2}	3×10^{-2}	2×10^{-1}
5 log	5×10^{-3}	3×10^{-3}	2×10^{-2}
6 log	5×10^{-4}	3×10^{-4}	2×10^{-3}
C. Poliovirus 3			
Non-detect value: 13.5 MPN $TCID_{50}/10\ell$			
4 log	4×10^{-1}	7×10^{-1}	9×10^{-1}
5 log	1×10^{-1}	1×10^{-1}	5×10^{-1}
6 log	1×10^{-2}	1×10^{-2}	7×10^{-2}
Non-detect value: 0 MPN $TCID_{50}/10\ell$			
4 log	4×10^{-1}	5×10^{-1}	9×10^{-1}
5 log	1×10^{-1}	8×10^{-2}	5×10^{-1}
6 log	1×10^{-2}	8×10^{-3}	7×10^{-2}

Yearly risks based on geometric mean virus levels more closely resembled maximum daily risks than did yearly risks based on arithmetic mean virus levels. This concurs with the findings of Rose and Gerba (1991) and supports the continued use of the geometric mean for calculation of mean yearly risks.

Successful application of microbial risk assessment in South Africa requires that attention be paid to a number of issues pertaining to monitoring of microbial water quality. The risk estimates presented in this study were relatively high when compared to EPA recommendations (Federal Register, 1989) and previous findings (Rose and Gerba, 1991; Rose *et al.*, 1991). The greatest restriction on detection of low risk levels was the volumes of water analyzed, which were not sufficient to detect low risks. Monitoring of larger volumes, at least 100ℓ, is necessary to detect risk levels comparable to that recommended by the EPA.

It may be possible to overcome this problem in the short-term by exploiting the relatively high sampling frequency practised at present (approximately twice per month) to estimate risks over a shorter time frame (*eg.* monthly). These risks may be compared with the EPA recommended yearly risk, or with risk recommendations which may be developed for South Africa. However, to gain the maximum benefit from the application of risk assessment methods to microbial monitoring data concentration of large volumes of water is necessary.

Other requirements for the use of microbial risk assessment include improved data describing the removal of viruses and other pathogens during water treatment to allow better estimates of levels in treated water to be derived from raw water levels. More comprehensive exposure data would also permit meaningful interpretation of the significance of risk estimates to community health.

ACKNOWLEDGEMENT

Permission for the use of viral monitoring data was kindly granted by the Rand Water Board, Johannesburg, South Africa.

REFERENCES

Cotruvo, J.A. (1987). Risk assessment and control decision for protecting drinking water quality. In: *Advances in Chemistry*, No. 214, J.H. Suffet and Murugan Maliyandi (Eds.). American Chemical Society, Washington DC, USA, 693-733.

Federal Register (1989). National Drinking Water Regulations: Filtration, Disinfection, Turbidity, *Giardia lamblia*, Viruses, *Legionella* and Heterotrophic Bacteria. Final Rule, 40 CFR, parts 141 and 142. *US Federal Register*, **54**, June 29 1989, 27486-27541.

Gerba, C.P. and Haas, C.N. (1988). Assessment of risks associated with enteric viruses in contaminated drinking water, In: *Chemical and Biological Characterisation of Sludges, Sediments, Dredge Soils and Drilling Muds.* SSTM STP **976**, J.J. Lichtenberg, J.A. Winter, C.I. Weber and L. Fradkin, (Eds.). American Society of Testing and Materials, Philadelphia, USA, 489-494.

Grabow, W.O.K. and Nupen, E.M., (1981) Comparison of primary kidney cells with the BGM cell line for enumeration of enteric viruses in water by means of a tube dilution technique. In *Viruses and Wastewater Treatment*, Goddard, M. and Butler, M. (Eds). Pergamon Press, Oxford, U.K., 253-356.

Haas, C.N. (1983). Estimation of risk due to low doses of microorganisms. A comparison of alternative methodologies. *Am. J. Epidəmiol.* **118**, 573-582.

Rose, J.B. and Gerba, C.P. (1991). Use of risk assessment for development of microbial standards. *Wat. Sci. Tech.* **24** (2), 29-34.

Rose, J.B., Haas, C.N. and Regli, S. (1991). Risk assessment and control of waterborne giardiasis. *Am. J. Publ. Hlth.* **81** (6), 709-713.

US EPA (1987). *The Risk Assessment Guidelines for 1986.* EPA/600/8-87/045/ US EPA Office of Health and Environmental Assessment, Washington, DC, USA.