30. Procedures of Choosing Wastewater Reclamation Methods to Assure Safety against Virus Infection

Presenter

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PROCEDURES OF CHOOSING WASTEWATER RECLAMATION METHODS TO ASSURE SAFETY AGAINST VIRUS INFECTION

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ABSTRACT

This study attempted to quantify the risk of enteric virus infection in case of wastewater reuse, and to clarify appropriate reclamation methods for safety. To assess the potential risk associated with the use of reclaimed wastewater in various applications, some exposure scenarios were assumed, and enteric virus concentrations in secondary effluents were monitored at ten wastewater treatment plants for 2 years.

The virus concentrations in secondary effluents were distributed according to a lognormal distribution, and annual infection risks (r) corresponding to the scenarios were calculated using the Monte Carlo method. Assuming some virus removal efficiencies (x), annual infection risks (r) were calculated and the relationship between virus removal efficiencies and annual infection risks (r=f (x)) was obtained for each scenario. The necessary virus removal efficiency (x0), satisfying the assumed acceptable annual risk (r0) under the scenario, was calculated using the equation r=f (x). A virus removal method satisfying the virus removal efficiency (x0) was chosen using the existing data of enteric virus removal efficiencies of several reclamation methods.

KEYWORDS

wastewater reclamation, enteric viruses, risk assessment, risk management, inactivation efficiency

INTRODUCTION

Sewerage systems collect and treat wastewater discharged from houses and industries, and so could be used to treat pathogens effectively and hence prevent them from spreading in cities.

The population served by sewerage systems reached 62% at the end of fiscal 2000, and about two-thirds of the water used by households now passes through sewerage systems. Therefore, treated wastewater is an alternative water resource in urban areas that offers a plentiful, stable supply of water.

The quantity of treated wastewater was 12.6 billion m^3 in fiscal 1999, of which 150 million m^3 was used outside of wastewater treatment plants, corresponding to 1.2% of the total treated wastewater. Among the reuse purposes, environmental use for recreation, scenery and water flow maintenance of rivers accounted for about half of the total usage, in addition to many cases of applying treated wastewater for flushing toilets. Thus, urban usage is the dominant form of wastewater reuse in Japan.

However, problems associated with protozoa and viruses have been identified and reported recently, and responses to such problems must be developed.

With this background, a Committee for Reclaimed Water Quality was established to investigate methods of ensuring the safety of reclaimed water against waterborne pathogenic viruses. This paper summarizes the research results of the Committee's activities.

POLICY FOR SECURING THE SAFETY OF RECLAIMED WATER

Securing the safety by reclamation methods

Continuous monitoring of the pathogenic virus concentration in reclaimed water is quite difficult, because it requires much skill and manpower. Therefore, to ensure the safety of reclaimed water against viruses, appropriate reclamation methods must be defined rather than regulating the target virus concentration.

Choosing reclamation methods based on infection risk assessment

For each potential application of reclaimed water, the amount of ingested water in a single exposure and the frequency of exposure were assumed, and the amount of ingested virus was calculated using the concentration distribution of viruses in the reclaimed water. Then, the infection risk was evaluated using the relationship between virus dose and infection probability, and reclamation methods that can achieve an acceptable risk were chosen.

SURVEY AND EXPERIMENTS

Virus concentration distribution in secondary effluent

At 10 wastewater treatment plants, enteric virus concentration was surveyed for two years, and the virus concentration distribution in the secondary effluent was estimated. The sample volume of the secondary effluent was 20 L, and two types of host cells, BGM and Hep-2, were used for virus detection.

The cumulative distribution of virus concentration is shown in Fig. 1, in which the x-axis represents the cumulative frequency expressed as a standard deviation and the y-axis is the virus concentration expressed as a logarithm. A linear relationship was obtained, and so it was assumed that the virus concentration distribution in secondary effluent follows a log-normal distribution. However, care is required because regional characteristics are not taken into account in the relationship, since all the data were analyzed together.

Virus removal efficiency of reclamation method

Pilot plant experiments were conducted to evaluate the virus removal efficiencies of several reclamation methods. Polio virus (vaccine strain) was added to treated wastewater, and experiments of disinfection with chlorine, ultraviolet light and ozone and sand filtration were carried out. The experiment results are shown in Tables 1 and 2.

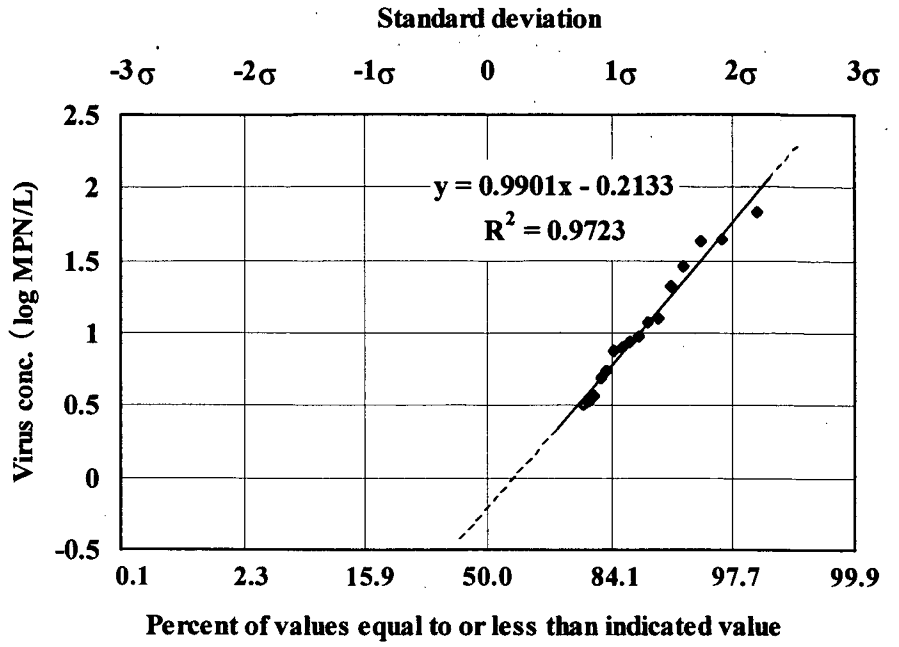

Fig. 1 Cumulative distribution of virus concentrations in secondary effluents

Table 1 Relationships between disinfection intensity and virus inactivation efficiency

Disinfection	Water sample	Turbidity (−)	Indicator of disinfection intensity	Virus inactivation ratio		
				1 log (90%)	2 log (99%)	3 log (99.9%)
Chlorination	Secondary effluent *1	3.0 - 3.5	Injection dose (mg/L)	15	−	−
			Ct value (min*mg/L) *4	150	−	−
	Tertiary effluent *2 + NH4-N *3	0.7	Injection dose (mg/L)	7.0	17	−
	Tertiary effluent *2	0.4 - 0.6	Injection dose (mg/L)	2.5	7.9	13
			Ct value (min*mg/L) *4	3.2	72	140
Ozonation	Secondary effluent *1	3.8	Injection dose (mg/L)	16	−	−
			Ct value (min*mg/L) *4	27	−	−
	Tertiary effluent *2	0.4 - 0.6	Injection dose (mg/L)	7.6	13	18
			Ct value (min*mg/L) *4	4.4	17	29
UV	Secondary effluent *1	3.5	UV dose (mWs/cm^2)	980	2,000	−
	Tertiary effluent *2	0.6	UV dose (mWs/cm^2)	560	1,200	1,800

−: No data. Significant figure: 2 digits

*1 Secondary treatment: HRT≒8 h

*2 Tertiary treatment: HRT≒13 h + sand filtration

*3 NH4-N was added to the final concentration of about 10 mg/L.

*4 "C" (= concentration) means residues, not dose. "t" (= contact time) is 15 min.

Table 2 Virus removal efficiency and turbidity reduction by sand filtration

Water Sample	Virus conc. (PFU/mL)	Virus removal ratio	Turbidity (−)
Before filtration (Secondary effluent)	9,000		3.5
Filtered sample (100m/day)*	4,000	0.36 log (56%)	1.1
Filtered sample (200m/day)*	6,500	0.14 log (28%)	1.2

Significant figure: 2 digits

DOSE-RESPONSE MODEL USED IN THE RESEARCH

The Beta-distributed probability model (Rose and Gerba, 1991) was used, which assumes that the infection ability of individual pathogens differs according to the number of pathogens ingested.

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

P: infection risk in a single exposure
D: ingested virus in a single exposure
$\alpha = 0.232$, $\beta = 0.247$ (value of the rotavirus)

PROCEDURE FOR SELECTING RECLAMATION METHOD

The procedure for choosing the reclamation method to secure the safety of reclaimed water is outlined in Fig. 2.

Firstly, assume the amount of ingested reclaimed water in a single exposure and the frequency of exposure, based on the conditions and situation of reuse.

Then, calculate the amount of ingested virus in a single exposure from the amount of ingested water and the virus concentration distribution, and obtain the infection risk in a single exposure using the virus dose-response relationship (procedure A).

The Monte Carlo method is applied, because the virus concentration shows the distribution (Tanaka et al., 1998). To obtain the annual risk of one person being infected, procedure A is repeated the same number of times as the exposure frequency per year (procedure B). Procedure B is repeated 500 times, to choose the value at 2.5% from the top as the annual infection risk of reuse (procedure C). Assuming several virus removal efficiencies of reclamation methods, which produces lower virus concentration distributions, the annual infection risk is calculated by following the series of procedures A, B and C.

From these calculation results, obtain the relationship between virus removal efficiency (x) and annual infection risk (r) in the form of r=f (x).

Determine the acceptable annual infection risk (r0), and calculate the necessary virus removal ratio (x0) to achieve the acceptable risk with the relationship of r=f (x).

Compare the removal efficiencies of reclamation methods with the required removal efficiency (x0), and then choose the appropriate method to achieve x0.

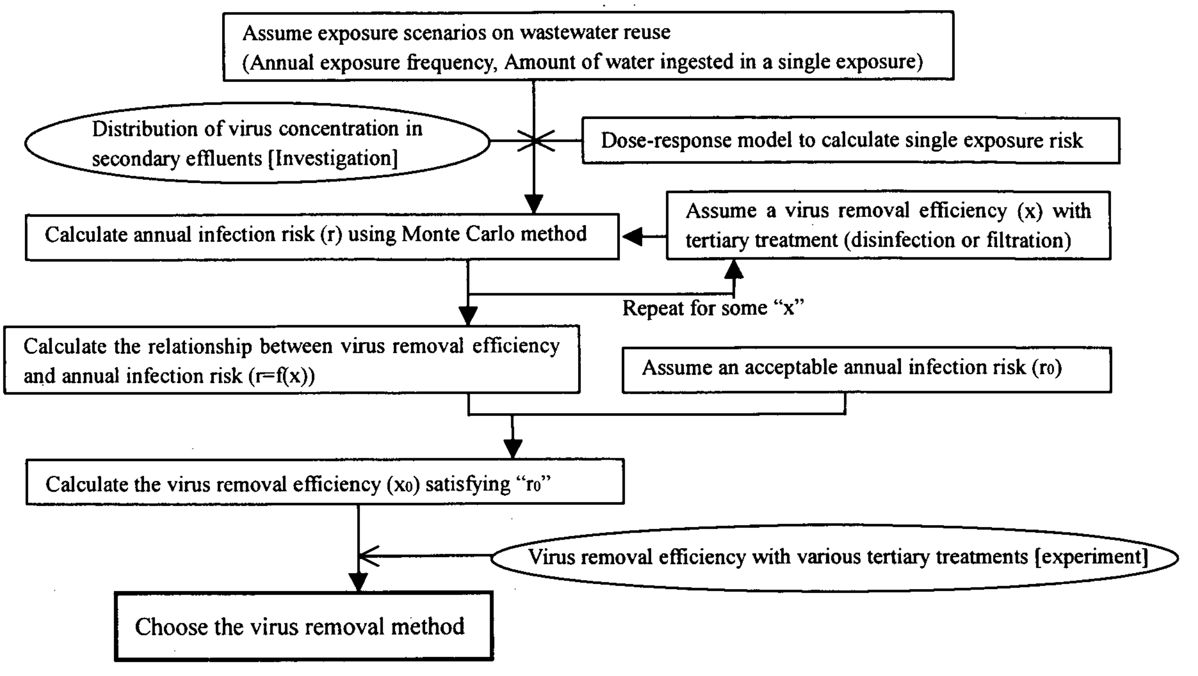

Fig. 2 Procedure to choose the virus removal method for wastewater reuse

EXPOSURE SCENARIOS AND RESULTS OF RISK CALCULATION

Setting exposure scenarios for each reuse purpose

Exposure scenarios for each reuse purpose, which are composed of ingested reclaimed water in a single exposure and the frequency of exposure, were set as shown in Table 3. The basis of the scenarios is explained in Table 4.

Table 3 Exposure scenarios assumed for wastewater reuse

Application purpose	Route of ingestion	Amount of water ingested in a single exposure (mL)	Exposure frequency per year
Recreational pond or stream (possible to swim)	Direct drinking	30	8
Recreational pond or stream (possible to bathe feet and hands)	Indirect ingestion from wet hands	0.3	20
Waterfall or fountain (large-scale)	Direct ingestion of spray	1	10
Fishing pond	Indirect ingestion from wet hands	0.2	20
Lawn irrigation	Indirect ingestion from wet hands	0.1	20
Toilet flush	Direct ingestion of spray	0.02	3

Table 4 Basis of the exposure scenarios (Table 3)

Application purpose	Amount of water ingested in a single exposure	Exposure frequency
Recreational pond or stream (possible to swim)	The amount of water in one gulp	Two days per week, for one month in the middle of summer
Recreational pond or stream (possible to bathe feet and hands)	Ten percent of the water on a wet hand	Two days per week, for 10 weeks in the summer
Waterfall or fountain (large-scale)	Ten percent of the water needed for humidifier (referenced from catalogue) 30 min. ingestion	One day per month, for 10 months excluding winter
Fishing pond	Half of the amount of water on a hand when a wet cylindrical paper-towel is grasped	About two days per month, for 12 months
Lawn irrigation	Ten percent of a golf player's exposure (referenced from another study (Asano et al., 1992); the golfer may touch irrigated greens and wet balls	About two days per month, for 12 months
Toilet flush	One-third of a drop of water from a 5 mL pipette	Using the toilet in the office once a day, 5 days per week, for 12 months. Ingestion possibility is once per 100 times flushing

Results of risk calculation

For each reuse purpose, several virus removal efficiencies were assumed, and annual infection risks were calculated based on the exposure scenario and the virus concentration distribution. The results are shown in Fig. 3.

CHOOSING THE RECLAMATION METHOD

To choose a reclamation method, the acceptable annual risk must be determined. However, as there is much argument as to the acceptable risk, we do not go into details here, but merely set three annual risks, 10^{-2}, 10^{-3} and 10^{-4}.

Then, using the relationship between virus removal efficiency and annual infection risk (Fig. 3), virus removal efficiencies required to achieve the annual risk were obtained as shown in Table 5. Reclamation methods satisfying the required virus removal efficiencies will be chosen from Tables 1 and 2.

The results of choosing reclamation methods, taking chlorine disinfection as the example, are shown in Table 6 for the acceptable risk of 10^{-3}.

In the case of possible swimming, the required virus removal efficiency was 3.8 logs, and no reclamation method within the conditions of Tables 1 and 2 could satisfy the removal efficiency. In this case, it is necessary to investigate the virus removal efficiency at a much higher disinfection intensity, or the reuse application itself must be reconsidered.

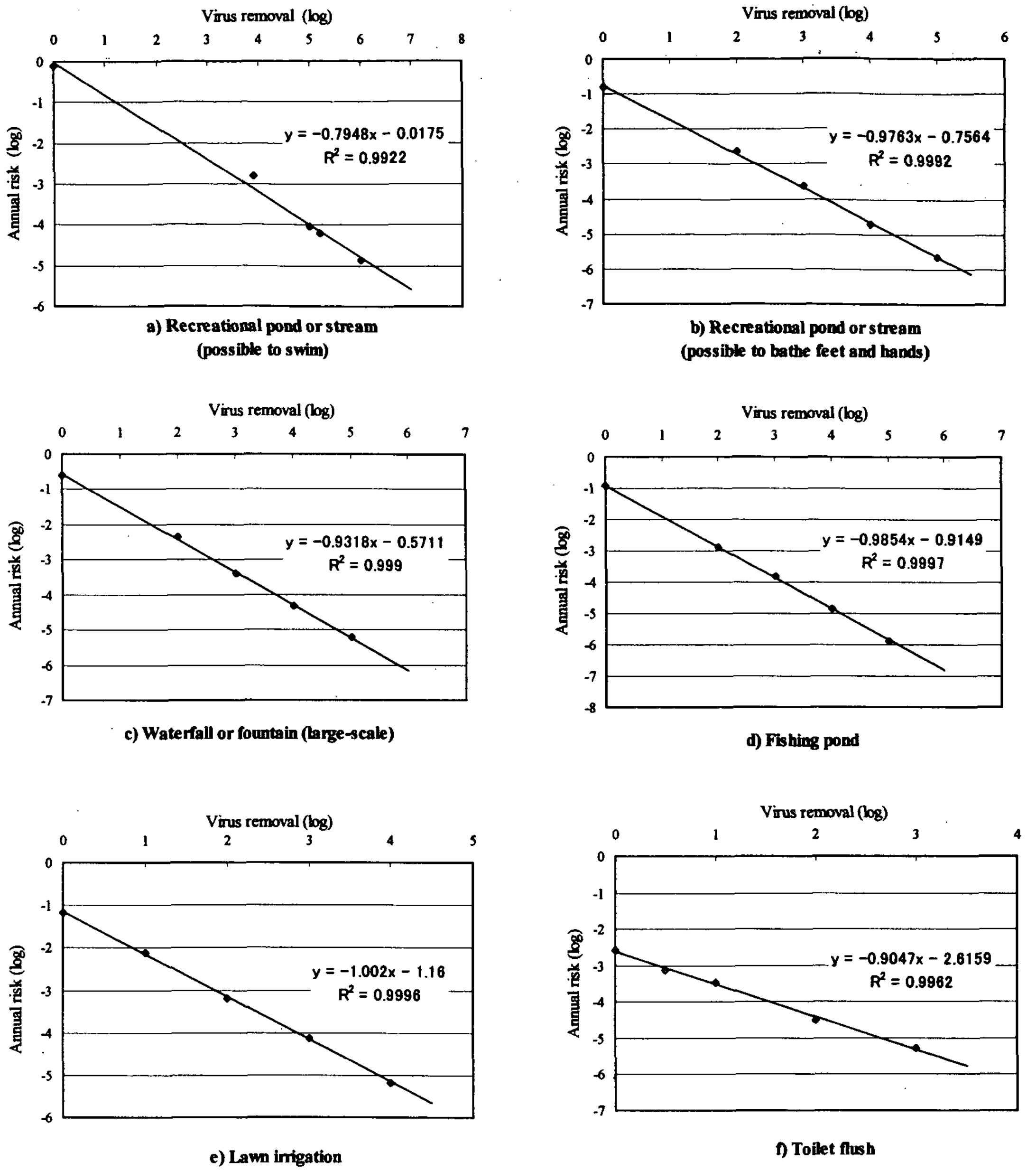

Fig. 3 Relationships between virus removal efficiencies and annual risks of infection

On the contrary, when reclaimed water is used for flushing toilets, the required virus removal efficiency is only 0.43 logs, and the chlorine dosage of 2.5 mg/L is sufficient for tertiary effluent.

In the case of possible bathing of hands and feet, the required virus removal efficiency is 2.3 logs, which could not be achieved if the source water is secondary effluent, but could be achieved with 17 mg/L of chlorine dose after sand filtration, even if the water contained NH_4-N.

Table 5 Required virus removal efficiencies to satisfy each annual risk of infection

Application purpose	Required virus removal efficiency		
	Annual risk: 10^{-2}	Annual risk: 10^{-3}	Annual risk: 10^{-4}
Recreational pond or stream (possible to swim)	**2.5 log** (99.68%)	**3.8 log** (99.98%)	**5.0 log** (99.999%)
Recreational pond or stream (possible to bathe feet and hands)	**1.3 log** (94.63%)	**2.3 log** (99.50%)	**3.3 log** (99.95%)
Waterfall or fountain (large-scale)	**1.5 log** (97.05%)	**2.6 log** (99.76%)	**3.7 log** (99.98%)
Fishing pond	**1.1 log** (92.06%)	**2.1 log** (99.24%)	**3.1 log** (99.93%)
Lawn irrigation	**0.84 log** (85.55%)	**1.8 log** (98.56%)	**2.8 log** (99.85%)
Toilet flush	(No need to remove)	**0.43 log** (62.42%)	**1.5 log** (97.05%)

The exposure scenarios are based on Table 3.

Table 6 Required chlorine disinfection intensity to satisfy annual risk of 10^{-3}

Application purpose	Required virus removal efficiency	Source water for disinfection	Required chlorine dose
Recreational pond or stream (possible to swim)	**3.8 log**	Secondary effluent	(Out of the range of Table 1)
		Tertiary effluent + NH_4-N	
		Tertiary effluent	
Recreational pond or stream (possible to bathe hands and feet)	**2.3 log**	Secondary effluent	(Out of the range of Table 1)
		Tertiary effluent + NH_4-N	**17** mg Cl/L
		Tertiary effluent	**8** mg Cl/L
Toilet flush	**0.43 log**	Secondary effluent	**15** mg Cl/L
		Tertiary effluent + NH_4-N	**7** mg Cl/L
		Tertiary effluent	**2.5** mg Cl/L

CONCLUSIONS

Procedures for choosing wastewater reclamation methods for ensuring safety against enteric viruses were developed based on a virus survey of 10 treatment plants, pilot plant experiments for virus removal, exposure scenarios for each reuse application and risk assessment.

Further research is needed to improve the procedure with detailed information about the virus concentration and infection ability, supported by appropriate methods for setting the acceptable risk.

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