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Microbial Risk Assessment using *E. coli* in UV Disinfected Wastewater Irrigation on Paddy

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Abstract

Water stress has become a major concern in agriculture. Korea suffers from limited agricultural water supply, and wastewater reuse has been recommended as an alternative solution. A study was performed to examine the effects of microorganism concentration in the ponded-water of a paddy rice field with reclaimed-water irrigation for evaluating the microbial risk to farmers and neighborhood children. Most epidemiological studies were performed based on an upland field, and they may not directly applicable to paddy fields. Beta-Poisson model was used to estimate the microbial risk of pathogen ingestion. Their risk value increased significantly high level after irrigation and precipitation. It implies that agricultural activities such as plowing, and fertilizing, and precipitation need be practiced a few days after irrigation considering health risks. The results about field application of the microbial risk assessment using *E. coli* showed difference according to monitoring time and treatment plot. Result of the microbial risk assessment showed that risk values of ground-water and reclaimed secondary wastewater irrigation were lower than directly use of wastewater treatment plants' effluent. This paper should be viewed as a first step in the application of quantitative microbial risk assessment of *E. coli* to wastewater reuse in a paddy rice farming.

Keywords: *E. coli*, Microbial risk, Paddy field, Wastewater reuse, Water quality

1. Introduction

Water shortage had became a major concern in agriculture. Therefore, wastewater reuse attracted public attention as alternative water sources in many countries. Especially, reuse for agriculture was already in operation by nearly around 120 countries.[1] Korea suffered from limited agricultural water supply, and wastewater reuse has been recommended as an alternative solution. Ministry of Environment Republic of Korea already announced their plan for increase of wastewater reuse to more than 10%.[2] If wastewater can be reused for agriculture that form 48% of total amount of water resource, utility value of that is more high.[3]

Reclaimed wastewater reuse have advantage to increase agricultural production. And it can also alleviate water-quality problem owing to discharge wastewater.[4,5] The effluent of wastewater treatment plants, however, generally contains high levels of microorganisms. Therefore, future treatments of wastewater may be required before agricultural reuse.[6] Paddy rice production requires a large volume of water. The fields are flooded before plowing and the water level is kept at 4 ~ 6 cm in shallow rice fields and as high as 10 cm in continuous flooding irrigation during the growing season.[7] A paddy field irrigated with reclaimed wastewater may have adverse health effects on farmers. It has been reported that the agricultural reuse of raw or partially treated wastewater may cause epidemiological problems among nearby populations and consumers of uncooked vegetables.[8] Farm workers and their children are especially likely to have direct contact with reclaimed wastewater through ingestion or aerosol inhalation. For instance, in the research of Blumenthal et al.(1996),[9] prevalence of the ascarid infection was higher among farm workers than in the control group, and excess infection was found in children than in adults.

The protection of public health in wastewater reclamation and reuse is one of the most important issues. Quantitative Microbial Risk Assessment (QMRA) is an important tool for assessing the risk involved in reclaimed water reuse, both in terms of the formulation of the risk analysis problem and in predicting the probability of infection in different scenarios.[10] And, QMRA is useful in quantifying risks of infection. QMRA is process that

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assumes adverse effect for human health and express quantify. QMRA was initially developed for buildup of scientific base that is necessary to establish water-quality standards of drinking water.[11] Its simplest form, consists of four steps, namely : hazard identification, exposure assessment, dose-response assessment and risk characterization.[4,12] And, revised framework by ILSI is introduced as case study of rotavirus disease process.[12,13]

US EPA (1992)[1] and WHO (2000)[14] presented the guidelines for reclaimed wastewater reuse. And, epidemiological research and microbial risk assessment for wastewater reuse was reported internationally. Microbial risk assessment about reclaimed wastewater reuse for agriculture was applied to many countries. But, they had limits for directly application at paddy rice field that take most portion of agricultural water use in Korea. Because, researcher focused their major concern on human health risk assessment for reclaimed wastewater that irrigated to paddy rice field. To address the aforementioned concerns, the *E. coli* concentrations in paddy fields irrigated with reclaimed wastewater was monitored for a 2-years field study (2007 ~ 2008). Microbial risk is estimated as a result of exposure to *E. coli* to evaluate human health problems for enteric diseases. The quantitative microbial risk assessment (QMRA) model was used to estimate the annual risk.[15]

2. Material and Methods

2.1. Experimental Plots and Sampling

The study area is test paddy of model operating region in hwasung city, Gyeong-gi province. Test paddy is arranged as 3 × 4 Randomized Block Design according to irrigation water (ground water, effluent of wastewater treatment plants, reclaimed wastewater). Byeong-jeom pumping station supplies Agricultural water sources in this area. And the major water sources of Byeong-jeom pumping station is effluent of Suwon wastewater treatment plants. The wastewater reclamation system is set up at supply system of pumping station. The reclamation system removes suspended solids and filtrates using bio-filter. And then, effluents are disinfected by UV-disinfection system.

E. coli concentrations were monitored in the 2007 and 2008 rice growing seasons. Triplicate water samples from paddy rice plots were mainly collected about two weeks. *E. coli* in the water samples were determined using Standard Methods. The density units are expressed with the most probable number (MPN) per 100 mL.

2.2. Microbial Risk Assessment

Hazard identification. E. coli is the most common member of the family of fecal coliforms, and is a representative microbilolgical indicator of water quality. The presence of *E. coli* also indicates the potential for co-existence of pathogenic organisms.[16] And, Hass et al. (1999)[13] was introduced QMRA methods using *E. coli* concentration. Application of QMRA for detectable whole microorganisms that is harmful to human health will give more accurate information. But, that is not only disadvantage on time and economy but also impossible in actual. Therefore, this study is focused on QMRA using *E. coli* concentration of paddy rice field for enteric disease.

Exposure assessment. Farm workers and their children are especially likely to have direct contact with reclaimed wastewater through ingestion or aerosol inhalation. In this study, contact pathway for microorganisms is limited to ingestion. Because major purpose of this study is that make a comparative study of risk for different irrigation water. Irrigated duration of paddy is about 100 days. And working duration of farm workers is shorter than that. The other side, their children is not exposed continually and directly as compared with farm workers. Therefore, total exposure duration of children is assumed to 30 days.[4]

Asano et al. (1992)[17] assumed that golfers are exposed to 1 mL of reclaimed water a day during handling of golf balls and their clothes. Since agricultural activity is practiced in pond water in paddy rice culture, the opportunity of contact with pathogens in a paddy rice field is more frequent than in golf areas.

Dose-response analysis. Dose-response analysis of QMRA is not executed by experiments on anmals unlike dose-response assessment for chemical. Toxic chemicals influence almost life but hazard of microorganisms will change as it may life. Therefore, dose-response model of QMRA must be based on human epidemiological research. The Beta-Poisson model can be used to quantify the risk of microbial ingestion. The model gives the following equation.[18]

$$P_I = 1 - [1 + \frac{N}{N_{50}}(2^{1/\alpha} - 1)] \quad (1)$$

In this equation, P_I is the risk of infection by ingesting pathogens in drinking water, N is the dose of microorganisms ingested, N_{50} is the microbial dose resulting in 50% infection, and α is a slope parameter. Human dose-response information was available when the exposure level was low, and the best-fit dose-response parameters for ingestion of *E. coli* were proposed to be $N_{50} = 8.60\times10^7$ and $\alpha = 0.1778$.[13] Eq. (2) gives the simplest assumption of the probability of morbidity that considers the probability distribution, age, health and status.

$$P_D = P_{D:I} \times P_I \quad (2)$$

P_D is the risk of an infected person becoming diseased or ill, and $P_{D:I}$ is the probability of an infected person developing clinical disease. To consider the probability of morbidity, the midpoint value of 50% was used in the calculation ($P_{D:I} = 0.5$).

The probabilities of farmers and neighboring children becoming infected were assumed to be two and five times greater, respectively, than those of the control population.[4] Because the agricultural population became aging, and neighboring children have high infection possibility in contrast with adults.[19] Blumenthal et al. (2001)[15] reported the four-fold excess of Ascaris infection in children aged 5~14 years after exposure to a secondary effluent.

Risk characterization. The process of risk characterization combines the information on exposure and dose-response into an overall estimation of likelihood of an adverse consequence.[20] In this study, a partial Monte Carlo simulation was performed using best-fit point estimates of infectivity (N_{50}, α) and probability normal distributions of *E. coli* concentration. The Monte Carlo simulation also shows the relative contribution of variability as a distribution.[21]

3. Results and Discussion

3.1. E. coli Monitoring in the Pond Water in a Paddy Field

In study area, there are total 12 paddy rice field. That are 4 according to each kind of 3 irrigation water, ground water, WWTP effluent and reclaimed wastewater. Monitoring is executed for irrigation periods until 12th Sep., 2008 since 17th May, 2007. Fig. 1 shows difference for coliform concentrations in each kind of irrigation water.

Coliform concentrations are variable according to monitoring period and each paddy. And, coliform concentrations was also different among each paddy fields irrigated same water. Jung et al. (2005a)[4] reported that rainfall or resuspending with disturbance of sediment can have an effect on background condition.

Significant variations of *E. coli* concentrations were observed within the sampling time during the rice growing season (Fig. 2). The reasons could be dilution by rainfall and agitation of sediments. *E. coli* tend to adsorb to the particles, and suspended sediments cause elevated concentrations of *E. coli* in the water body.[16] At early period of irrigation, concentration of coliform groups show high level. This may be caused by intensive farm working included fertilizing, tilling and intensive irrigation at that time. And concentrations of whole paddy fields at 22th Jul. also show high level. This period is the rainy spell in early summer in Korea. At that time, some organic matter may be came into paddy rice field by surface flow (incoming of non- point sources by flushing of storm-water). But datum that are doubted as disturbed were not excluded. Because, farm working is surely bring about disturbance of condition in paddy field. And farmers work in these condition.

3.2. Microbial Risk Assessment

Table 1 tabulates the annual and monthly risk values estimated. The Monte Carlo simulation was performed based on 10,000 trials, and the risk values were used in the 95% confidence region. Examples of the simulation out-puts are shown in Figure. 3.

Tanaka et al. (1998)[21] calculated that the annual risk ranged from 10^{-3} to 10^{-5} using the Monte Carlo simulation in the case of infection resulting from food crop irrigation with secondary effluents. The risk value was generally maintained at a similar level in all treatments.

The annual risk value of farmer for exposure to paddy rice field irrigated with WWTP effluent was about 3.34×10^{-3}, higher than 9 times of the values for ground water, 3.60×10^{-4}. And monthly risk values of WWTP effluent irrigation showed about 2.5~17 times high level as compared with risk values of ground water irrigation at same time. Add to this, maximum monthly risk values of WWTP effluent irrigation showed 6.57×10^{-3}. The other side, annual risk value of reclaimed wastewater (8.57×10^{-4}) showed high level as about two times of ground water irrigation. Monthly risk values of reclaimed wastewater irrigation showed about 1~8 times high level as compared with risk values of ground water irrigation at same time. Monthly risk values of reclaimed wastewater irrigation showed similar level to ground water irrigation excluding July. When WWTP effluent is irrigated on paddy rice field, the annual risk value is higher than 3 times of reclaimed water. Jung et al. (2005a)[4] reported their results of pilot-scale study that reclaimed water irrigation can decrease risk value as 10^{-4}-10^{-5}. And the results of this study are showed reasonable considering field-scale study.

The other side, children were found to have a lower risk of *E. coli* infection, although young children are influenced by environmental exposure to pathogens than adults. This is result caused by difference of assumed periods between children and adult. But children have not yet developed proper sanitary habits such hand washing. Object-to-mouth and mouth-to-mouth contact are much greater among children than adults.[19] Therefore, special

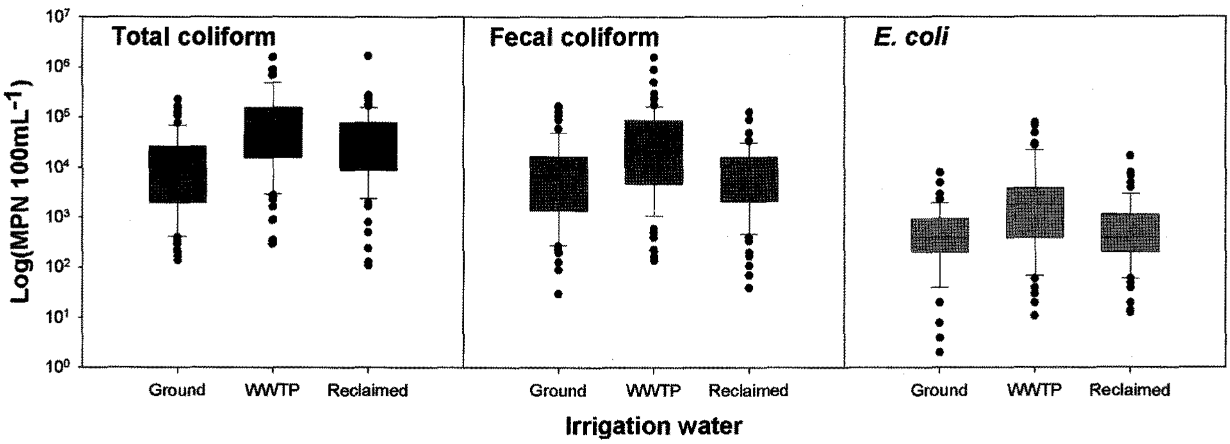

Fig. 1. Comparison of coliform concentrations in each kind of irrigation water.

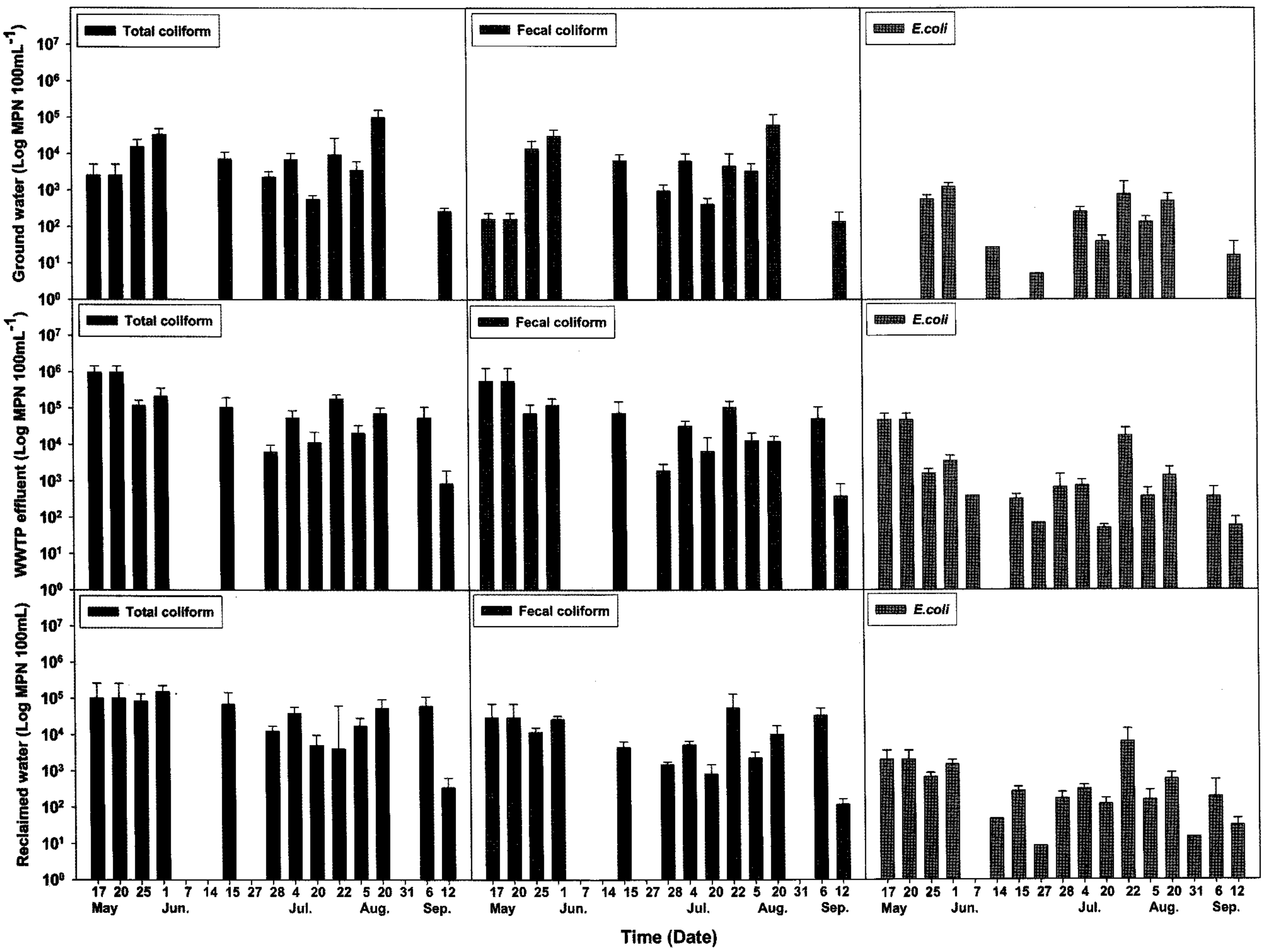

Fig. 2. Variation of microorganism concentration according to period.

Table 1. Annual and monthly risk value (95% confidence region, risk value $\times 10^{-4}$)

	Farmer			Children		
	Ground water	WWTP effluent	Reclaimed water	Ground water	WWTP effluent	Reclaimed water
May	8.19	65.71	9.61	6.14	49.28	7.21
Jun.	2.39	6.08	2.53	1.80	4.56	1.90
Jul.	2.32	39.95	19.46	1.74	29.96	14.60
Aug.	1.28	3.62	1.51	0.96	2.71	1.14
Sep.	0.62	10.94	1.20	0.46	8.21	0.90
Annual	3.60	33.37	8.57	2.70	25.03	6.43

and continuous care is required to protect health of children. The range of 10^{-4} to 10^{-6} was considered a reasonable level of risk for communicable disease transmission, and annual risk values of above 10^{-4} were considered high for infection.[18] When WWTP effluent is irrigated on paddy rice field, the risk value is continuously higher than 10^{-4}. This is level that infection can be occurred.

Figure 4 shows monthly variation of risk values. Risk values during the initial cultivation and the rainy season (May and July) were higher. Therefore, this period required special management and caution to protect human health. Jung et al. (2005b)[4] reported that *E. coli* concentration on paddy rice field was rapidly decreased at clear condition, and was confirmed definite decrease within 24 hr at rainy condition. Therefore, risks 1 h and 24 h after irrigation were shown to be 10^{-4}-10^{-5} and 10^{-5}-10^{-6}, respectively. Since the annual risk after 24 h significantly decreased after irrigation, execution of agricultural activity is thought to be safer 1 to 2 days after the paddy field is irrigated with reclaimed wastewater.[4,10]

4. Conclusions

The protection of public health in wastewater reclamation and reuse is one of the most important issues. QMRA is an important tool for assessing the risk involved in reclaimed water reuse, both in terms of the formulation of the risk analysis pro-

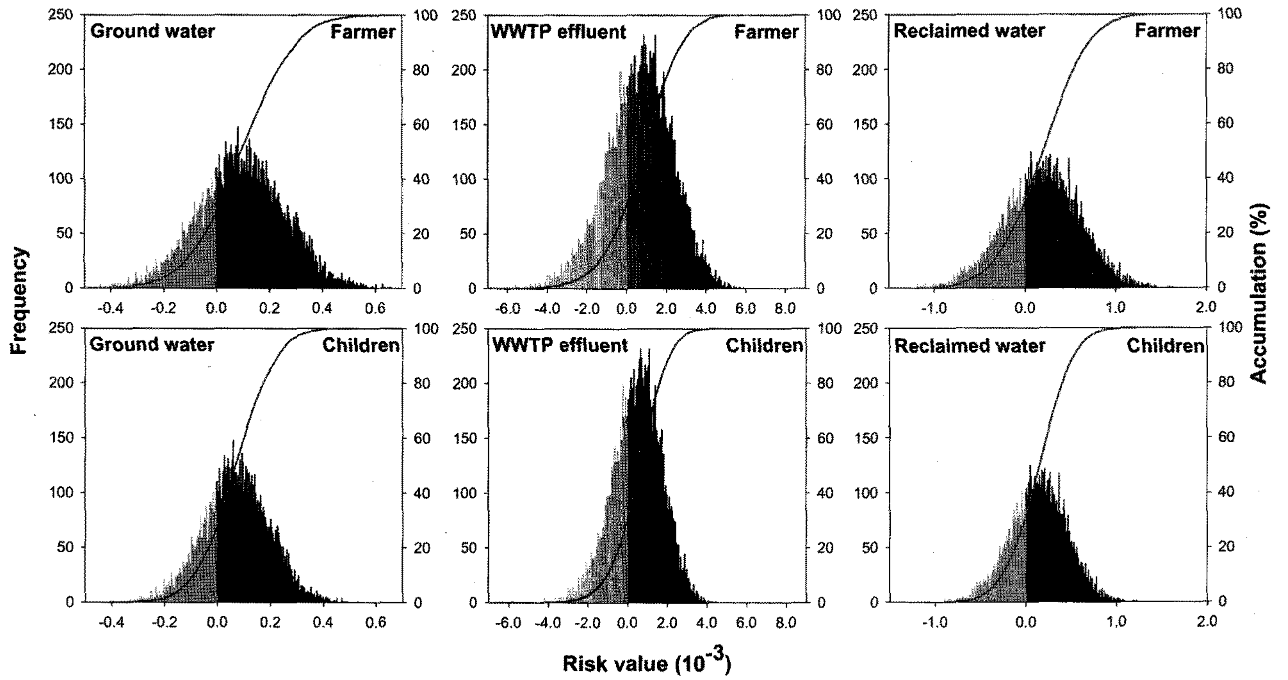

Fig. 3. Microbial risk assessment by Monte-Carlo analysis.

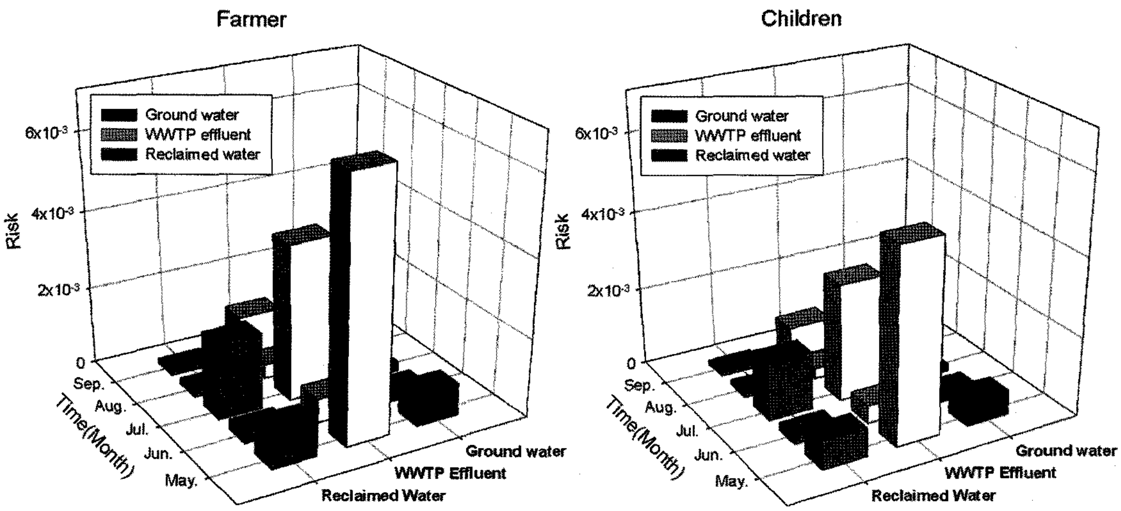

Fig. 4. Variation of risk values by monthly average *E. coli* concentration.

blem and in predicting the probability of infection. This study is focused on QMRA using *E. coli* concentration of paddy rice field for enteric disease. And the major purpose is that make a comparative study of risk for different irrigation water, ground water, WWTP effluent and reclaimed wastewater. Risks after irrigation were shown to be 10^{-3}~10^{-5}, respectively. But, the result of field application of microbial risk assessment using *E. coli* shows difference according to monitoring time and treatment plot. Since the annual risk, execution of agricultural activity is thought to be safer 1-2 days after the paddy field is irrigated with reclaimed wastewater. Irrigation with reclaimed wastewater with UV-disinfection significantly reduces as compared with WWTP effluent. But reflected datum are about only 2-years. Thus, continuously accumulation of data is required for more accurate assessment. And, more detailed and confidential study is required through consideration of various exposure pathway and immediate detecting of pathogenic microorganisms including *Salmonella, Shigella* and Human enteric viruses.

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