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The Synergistic Toxicity and Environmental Risk Assessment of DBPs in Reclaimed and Disinfected Wastewater Based on Model Organism

Tian-le Tang, Wen-hao Tang, Yang Yang, Ya-wen Chen, Fen-fang Yu, Juan-juan Bai, Zhang-dong Xiong
Hainan University, College of Environment and Plant Protection
Renmin Av. 58, Haikou, Hainan, PR China
ttl-0114@163.com; twh1229@163.com; yangyang_0221@hotmail.com; logne5@qq.com; 542770834@qq.com; 827328310 @qq.com; 524821586@qq.com

Extended Abstract

Reclaimed water is of great significance for water resource shortage. However, in the process of disinfection, disinfectants and some trace dissolved organic matters (DOMs) in the reclaimed water react with each other, thus generating disinfection byproducts (DBPs), which are affecting organism and environment. It was indicated in many studies that DBPs were a potential threat to people's health and eco-environment. The synergistic toxicity of various DBPs is difficult to be shown through chemical analysis, but it shows great superiority to research and assess the synergistic toxicity and environmental risk of DBPs on the basis of model organisms.

The study was conducted through biology toxicological tests to learn the toxic effects of reclaimed water on exposed zebrafish embryos. The reclaimed water was the disinfected secondary settling tank effluent from a municipal wastewater treatment Plant (MWTP) of a coastal city in Hainan, China, and it was disinfected by chemical disinfectants chloramines, chlorine dioxide, sodium hypochlorite, ozone alone, or by chemical disinfectants combined with ultraviolet radiation. Analytic hierarchy process (AHP) was applied to establish an assessment model of hazard classification based on the toxicological endpoints of exposed zebrafish embryos. Meanwhile, synergistic toxicity of DBPs and threats of reclaimed water disinfection were assessed by the model.

And the findings are as follows.

(1) According to the toxicological endpoints of zebrafish embryos in the tests, an assessment model of ecological security was established. The model could evaluate the security of one pollutant or one species of pollutants which exist in the synergistically polluted environment with unknown concentrations directly, but not analyze the species and concentration of pollutants.

Observed endpoints of zebrafish embryos were separated to lethal endpoints (*I*-type) and sublethal endpoints (*II*-type). Ecological risk index *P* was calculated with weighted sum of *I*-type and *II*-type, and the calculation formula is shown below.

$$P = \sum \mathrm{f}_I \cdot D_I + \sum_{\mathrm{n}} \mathrm{f}_{II\mathrm{n}} \cdot D_{II\mathrm{n}} \quad (1)$$

f_I—weight of *I*-type (i.e., weight of mortality)
D_I—mortality
n—number of *II*-type
$\mathrm{f}_{II\mathrm{n}}$—weight of *II*-type
$D_{II\mathrm{n}}$—incidence of *II*-type

Table. 1. 1. The establishment and weight distribution of ecological security assessment model.

	Factors	Lethal endpoints（0.5987）	Sublethal endpoints（0.4013）	Combination weight
Lethal endpoints（*I*-type）	mortality	1.0000		0.5987
Sublethal endpoints（*II*-type）	deformity of yolk sac		0.3132	0.1257
	pigmentation-reduction		0.3132	0.1257
	hatching-retardation		0.1525	0.0612
	malformation of tail		0.1106	0.0444
	heart beat-retardation		0.1106	0.0444

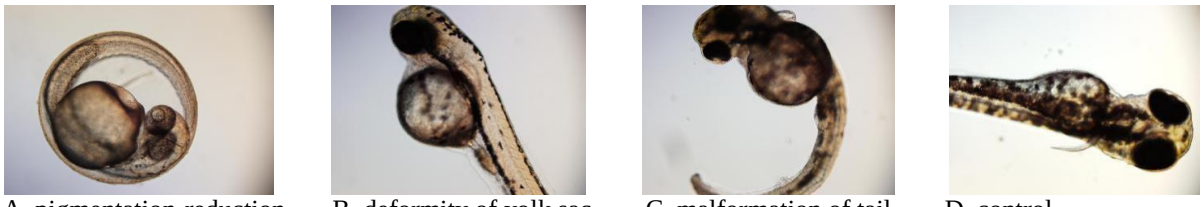
Table. 1. 2. Hazard classification.

Hazard index	≤0.1	(0.1,0.2]	(0.2,0.3]	>0.3
Hazard degree	I	II	III	IV
Hazard intensity	slight	moderate	less strong	strong

(2) Comparing with the control, the toxicological endpoints (such as deformity of yolk sac, heart beat-retardation, pigmentation-reduction, hatching-retardation, malformation of tail, etc) appeared after zebrafish embryos exposed in the secondary settling tank effluent disinfected by chloramines, chlorine dioxide, sodium hypochlorite, ozone alone. The order of toxicities of the disinfectants based on the mortality of exposed zebrafish embryos were chlorine dioxide < ultraviolet radiation < the secondary settling tank effluent (i.e., non-disinfected, control) < chloramines < ozone < sodium hypochlorite, from the least toxic one to the highest toxic.

Table. 2. The effects of reclaimed water with different disinfectants on embryonic mortality.

Mortality	8h	24h	48h	72h
Control	0.000 C	0.042 D	0.042 F	0.042 F
The secondary settling tank effluent (non-disinfected)	0.000 C	0.167 B	0.167 BC	0.167 CD
Sodium hypochlorite	0.042 A	0.250 A	0.271 A	0.292 A
Chlorine dioxide	0.000 C	0.083 CD	0.083 E	0.083 E
Chloramines	0.021 B	0.021 D	0.167 BC	0.188 BC
Ozone	0.000 C	0.188 B	0.188 B	0.208 B
Ultraviolet radiation	0.021 B	0.104 C	0.146 C	0.146 D



A. pigmentation-reduction B. deformity of yolk sac C. malformation of tail D. control

Fig.. 1. 1. Teratogenic development of exposed zebrafish embryos

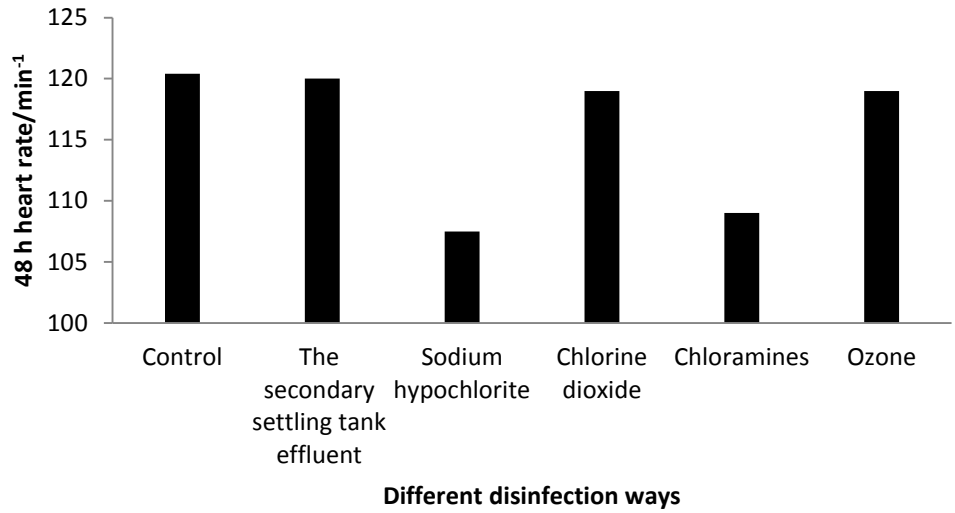


Fig. 1. 2. The effects of reclaimed water with different disinfectants on embryonic heart rate

(3) The hazard intensity of different disinfection ways were chlorine dioxide and ultraviolet radiation caused slight hazard (hazard degree was I), chloramines caused moderate hazard (hazard degree was II), sodium hypochlorite caused less strong hazard (hazard degree was III).

Table. 3. Hazard classification and assessment of different disinfection ways.

	Control	The secondary settling tank effluent	Sodium hypochlorite	Chlorine dioxide	Chloramines	Ozone	Ultraviolet radiation
Hazard index	0.02	0.10	0.23	0.07	0.17	0.16	0.10
Hazard degree	I	I	III	I	II	II	I
Hazard intensity	slight	slight	less strong	slight	moderate	moderate	slight

(4) Disinfection by ultraviolet radiation combined with chemical disinfectants could weaken the biotoxicity compared with simplex chemical disinfection. It was the most obviously in ultraviolet radiation combined with sodium hypochlorite versus sodium hypochlorite alone. The differences between ultraviolet radiation combined with chloramines and chloramines only was not significant. The toxicities of ultraviolet radiation combined with chlorine dioxide and single chlorine dioxide was remarkable indiscrimination. The hazard of ultraviolet radiation combined with ozone was lower than ozone.

Table. 4. Hazard classification and assessment of different disinfection ways

	Sodium hypochlorite	UV+Sodium hypochlorite	Chloramines	UV+Chloramines	Chlorine dioxide	UV+Chlorine dioxide	Ozone	UV+ Ozone
Hazard index	0.23	0.14	0.17	0.16	0.07	0.07	0.16	0.11
Hazard degree	III	II	II	II	I	I	II	II
Hazard intensity	less strong	moderate	moderate	moderate	slight	slight	moderate	moderate

(5) The diluting tests of disinfected reclaimed-wastewater were carried out where zebrafish embryos was exposed to it. The results showed that the toxicity of DBPs, which formed by disinfection with sodium hypochlorite, was stronger, but the toxicity decreased markly after dilution. When exposure water sample was diluted to 8-fold, the hazard degree fell to I from III. Therefore, if the discharge fort of disinfected reclaimed-wastewater is placed in an open water which owns better flowability, it will lead to less damage to eco-environment.

Table. 5. Hazard classification and assessment of diluted water disinfected with sodium hypochlorite.

	Control	Non-diluted	2-fold-diluted	4-fold-diluted	6-fold-diluted	8-fold-diluted	10-fold-diluted
Hazard index	0.03	0.29	0.23	0.21	0.17	0.07	0.04
Hazard degree	I	III	III	III	II	I	I
Hazard intensity	slight	less strong	less strong	less strong	moderate	slight	slight