Research Progress on Risk Assessment of Emerging Contaminants in Aquatic Environment

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Abstract—The rapid industrialization process has brought about explosive growth in the types of chemicals and the widespread and extensive usage of chemicals. These chemicals enter into the aquatic environment with their application in industry and daily life, posing a security threat to natural water bodies and public health. It is necessary and urgent to carry out risk assessment of these new pollutants or micro-pollutants in water. Therefore, this paper reviewed the research progress and development direction of health risk assessment and ecological risk assessment of emerging contaminants in aquatic environment, and prospected the research and application in China. This paper proposes that it is necessary to deeply study the public health effects, environmental effects and migration and transformation characteristics of these emerging contaminants in water, and to understand their toxicological effects, so as to establish a sound risk assessment benchmark and method as soon as possible to help water resources management and water security.

1. Introduction

With the explosive growth of chemical species brought by industrial production and the rapid development of aquatic environment analysis and detection technologies, more and more pollutants are detected in water systems, from typical persistent organic pollutants (POPs) such as organochlorine pesticides, polycyclic aromatic hydrocarbons and polychlorinated biphenyls, to emerging contaminants of concern in recent years, including emerging POPs such as fluorine-containing organic compounds, pharmaceuticals and personal care products (PPCPs), endocrine disruptors chemicals (EDCs), disinfection by-products (DBPs), engineered nanomaterials, microplastics. In recent years, these unconventional pollutants have been detected in sewage systems, surface water and even drinking water, and are present in the water environment at relatively low concentrations, often referred to as micro-pollutants, or emerging contaminants. Due to the long-term existence of these emerging contaminants in aquatic environment, affecting the safety of aquatic ecology and public health, it is necessary to pay attention to and study their potential risks.

Risk assessment is originated in several developed countries in the 1970s. The United States has the most in-depth research and regulations on risk assessment. In 1976, the US EPA published Guidelines for Carcinogen Risk Assessment, proposing the method of toxicity identification to carry out risk assessment. In 1983, the U.S. National Academy of Sciences (NAS) released "the Redbook", Risk Assessment in the Federal Government, which proposed a four-step risk assessment framework, including hazard identification, dose-response relationship assessment, exposure assessment, and risk characterization[1]. Since then, the US EPA, the World Health Organization (WHO), the United Nations Environment Programme (UNEP) and other organizations issued a series of related norms and guidelines in terms of risk assessment on the four-step basis. At present, the scientific system of risk assessment has been basically formed, including human health risk assessment and ecological risk assessment.

In recent years, with the continuous development of pollutant analysis and detection technology, the research on risk assessment of emerging pollutants is increasing. Using this technology to evaluate the human health risk and ecological risk of urban sewage recycling is helpful to provide research support for aquatic environmental safety, water resource management and safe usage.

2. Health Risk Assessment of Micropollutants

In the studies of health risk assessment of micro-pollutants or emerging pollutants, the exposure and risk of drinking water can not be ignored due to its direct effect on the human body, so it has attracted attention earlier. Deng et al.[2] detected and analyzed 5 genotoxic substances and 12 somatic toxic substances in the tap water of a drinking water pipe network in a Pearl River Delta city in China.

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The health risk assessment model recommended by the US EPA was used to carry out the health risk assessment under the drinking water pathway, and the analysis showed that the carcinogenic risk ranged from 3.10×10^{-10} to 2.92×10^{-5}, and the non-carcinogenic risk ranged from 8×10^{-13} to 9.5×10^{-12}. The health risk level exceeded the acceptable level limit. Their further study indicated that the carcinogenic risk, non-carcinogenic risk and total health risk caused by these pollutants in three water bodies ranked from high to low as source water > tap water > finished water[3]. Owen et al.[4] conducted a risk assessment of children's health in two counties in New Jersey, the United States. Based on environmental monitoring data, the carcinogenic and non-carcinogenic risks of 19 pollutants in three categories of organic matter, inorganic matter and emerging pollutants were evaluated. Three types of human-water contact scenarios considered include intaking of untreated groundwater from contaminated wells, accidentally intaking of Delaware River water in entertainment contact and eating fish from the Delaware River. Through the assessment of the health risks caused by various pollutants in three scenarios, it was found that arsenic and trichloroethylene in well water caused the highest ecological risk, and the carcinogenic risk value from As reached 2.13×10^{-3}. Wu et al.[5] monitored 48 organic micro-pollutants in four drinking water sources in Henan, China and calculated the health hazard index (HI) of micro-pollutants to adults and children through exposure to drinking water. The results showed that the HI ranges of adults and children were 2.01×10^{-8}~3.16×10^{-4} and 4.35×10^{-8}~6.82×10^{-4}, respectively, and the health risks were at a safe level (HI<1).

Groundwater has an impact on drinking water sources, and in areas where groundwater is used as part of drinking water sources, the presence and health risks of micro-pollutants in groundwater are also worthy of attention and study. Tian et al.[6] detected 126 kinds of organic micro-pollutants and 25 kinds of metals from 175 groundwater samples collected from 166 wells in rural areas in China. Using the health risk assessment model of the United States EPA, the health risk assessment of some detected pollutants through oral intake was carried out. Combined with Monte Carlo simulation analysis, it was concluded that the carcinogenic risk of pollutants in 91% of the sampling points had a 90% probability of exceeding the safety level (10^{-6}), and the carcinogenic risk in 17 % of the points had a 90 % probability of exceeding 10^{-4}, which was at a high carcinogenic risk level. Nitrobenzene, diethylhexyl phthalate, SMX, Li, As, Sr and Cr were the primary pollutants causing health risks.

Although the research on the occurrence of micro-pollutants in rivers and lakes and sewage treatment systems has gradually increased, there are not enough studies on the occurrence of micro-pollutants in sewage treatment and reuse systems and the health risk assessment of micro-pollutants in surface water and sewage treatment systems. After the reclaimed water of sewage treatment plant is reused in the urban river system, the water quality of the river water body is directly affected by the reclaimed water of the sewage treatment plant, and the contact with the public is frequent and the situation is complex. The research on the occurrence and health risk of the corresponding micro-pollutants is of great significance and needs to be carried out urgently, so as to ensure the safety of water resource.

3. Ecological Risk Assessment of Micropollutants

The common methods of ecological risk assessment mainly include quotient method and probability method. The ecological risk assessment of micro-pollutants is mostly based on the risk quotient method, using the ratio of measured environmental concentrations (MECs) or predicted environmental concentrations (PECs) to predicted no effect concentrations (PNEC) or semi-maximum effect concentrations in toxicological data. Risk quotient (RQ) is calculated as RQ = MEC / PNEC or PEC / PNEC. If RQ is greater than 1, it indicates high risk, 0.1 ~ 1 indicates medium risk, less than 0.1 indicates low risk or no risk[7, 8]。

Probabilistic risk assessment is a relatively new ecological risk assessment method, which has been gradually applied. Probabilistic risk assessment method is to treat each exposure concentration and toxicity data as independent observed values, based on which the statistical significance of probability is considered. Probabilistic risk analysis method, considering the uncertainty and variability of environmental exposure concentration and toxicity value, is a more intuitive, reasonable and non-conservative method to estimate risk. Probabilistic risk assessment methods usually include the margin of safety method and probability curve distribution method[9]. The Margin of Safety (MOS) method characterizes the ecological risk of pollutants by comparing the exposure concentration of pollutants with the margin of safety of biological communities[10]. The margin of safety method is based on the ratio of species sensitive distribution (SSD) to exposure concentration distribution (ECD), which characterizes the overlap of exposure distribution and toxicity distribution to further characterize the risk value. Probabilistic curve distribution method is to analyze the probability distribution curve of exposure concentration and toxicity data to investigate the degree of toxicity of pollutants to organisms and the corresponding risks. The risk assessment results can be presented in the form of a continuous distribution curve, which helps to determine the level of protection according to the proportion of affected species in risk management, fully considering the uncertainty and variability of environmental exposure concentration and toxicity value[10, 11]。

Wen et al.[12] used the risk quotient method to assess the ecological risk level of PPCPs in municipal wastewater, and the results showed that diclofenac had high risk. Zhang et al.[13] analyzed the distribution of PPCPs in surface sediments and water samples of 13 main tributaries of the Haihe River Basin and studied the risk of PPCPs pollutants to organisms in the Haihe River Basin. The results showed that PPCPs were detected in the Haihe River Basin with high content, and the Haihe River Basin had been polluted by PPCPs. Li et al.[14] evaluated the environmental risk of PPCPs in rivers of Shanghai, and found that triclosan was ubiquitous in surface water of Shanghai, and the environmental risk was high. Zhou et al.[15] studied the content level and spatial distribution of 41 antibiotic compounds in 13 sampling sections of the Guangzhou section of the Pearl River, and conducted the ecological risk assessment of 13 detected antibiotic compounds by risk quotient method. The results showed that the ecological risk of single antibiotic was higher than that of other antibiotics. Yang et al.[16] carried out ecological risk assessment of 4 kinds of organic micro-pollutants in 10 sites of the Yangtze River by using the risk quotient method, and the RQ value of each pollutant in each site ranged from 2.50×10^{-7} to 1178.22. Among all kinds of micro-pollutants, the ecological risk of PAHs, PCBs, OCPs and PPCPs was the highest, and the mixed ecological risk caused by all kinds of micro-pollutants was at a high-risk level.

4. Conclusion

The research and control of trace toxic and harmful pollutants, especially emerging contaminants, started relatively late in China. Therefore, it is necessary to further study the public health risks and ecological risk caused by emerging contaminants and their migration and transformation in water, understand the toxicological effects and establish a toxicity effect assessment method for low concentration, long-term toxicity and combined pollution. A recognized evaluation benchmark based on human health and ecological environment safety need to be established, so as to avoid the uncertainty of risk assessment results. In addition, the further research on exposure parameters is also in urgent demand. The health risk assessment methods and ecological risk assessment methods used for emerging contaminants are still relatively traditional and difficult to adapt to the increasingly complex actual situation. Therefore, it is necessary to establish a risk assessment method suitable for local departments based on the actual situation in China and the frontier risk assessment methods.

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