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Development of water quality criteria of ammonia for protecting aquatic life in freshwater using species sensitivity distribution method

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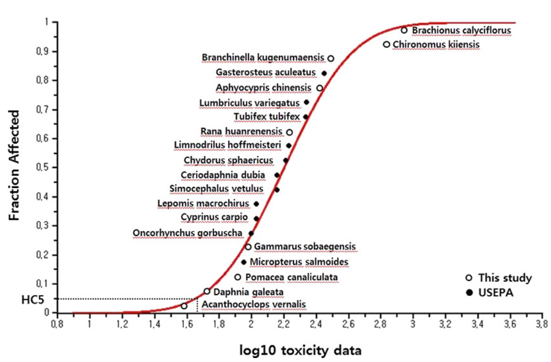
HIGHLIGHTS

- The species sensitivity distribution (SSD) method was used for ammonia guideline.
- *Acanthocyclops vernalis* and *Daphnia galeata* were the most sensitive in the SSD.
- The guideline for ammonia was found to be 22 mg/L at pH 7 and 20 °C.
- 0.09–0.51% of monitoring data in rivers and lakes in Korea exceeded this guideline.
- Our results can provide the basis for introducing the ammonia standard in Korea.

GRAPHICAL ABSTRACT



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ABSTRACT

Ammonia is deemed one of the most important pollutants in the freshwater environment because of its highly toxic nature and ubiquity in surface water. This study thus aims to derive the criteria for ammonia in freshwater to protect aquatic life because there are no water quality criteria for ammonia in Korea. Short-term lethal tests were conducted to perform the species sensitivity distribution (SSD) method. This method is widely used in ecological risk assessment to determine the chemical concentrations to protect aquatic species. Based on the species sensitivity distribution method using Korean indigenous aquatic biota, the hazardous concentration for 5% of biological species (HC_5) value calculated in this study was 44 mg/L as total ammonia nitrogen (TAN). The value of the assessment factor was set at 2. Consequently, the criteria for ammonia were derived as 22 mg/L at pH 7 and 20 °C. When the derived value was applied to the monitoring data nationwide, 0.51%, 0.09%, 0.18%, 0.20%, and 0.35% of the monitoring sites in Han River, Nakdong River, Geum River, Youngsan River, and lakes throughout the nation, respectively, exceeded this criteria. The Ministry of Environment in Korea has been considering introducing water quality standard of ammonia for protecting aquatic life. Therefore, our results can provide the basis for introducing the ammonia standard in Korea.

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Table 1
Characteristics of Korean native aquatic species in laboratory toxicity tests with different total ammonia nitrogen (TAN) concentrations.

Scientific name	Taxonomic grouping	Source	pH	Measured concentration of TAN (mg/L)
Aphyocypris chinensis	Fish	Hatchery	6.5	1.02, 28.8, 117, 234, 466, 978
			7.2	1.66, 54.9, 112, 229, 390, 770
			8.0	1.21, 3.38, 9.62, 20.7, 36.0,72.1
Pomacea canaliculata	Mollusca	Stream	6.4	0.100, 26.6, 69.7, 126, 280, 611
			7.0	0.100, 7.24, 15.1, 32.4, 69.3, 137
			7.8	0.100, 2.45, 5.58, 13.4, 30.5, 60.7
Daphnia galeata	Cladocera	Laboratory culture	7.2	0.100, 19.2, 33.0, 64.0, 69.0, 94.3
			7.6	0.100, 12.1, 29.9, 41.4, 58.2, 77.4
			8.0	0.100, 10.9, 19.0, 26.0, 32.9
Rana huanrenensis	Amphibian	Valley	7.3	0.450, 58.2, 66.8, 200, 269, 344
Gammarus sobaegensis	Amphipoda	Valley	7.8	0.100, 3.70, 6.46, 17.9, 37.6, 80.2
Acanthocyclops vernalis	Copepoda	Stream	7.7	0.100, 10.4, 17.0, 44.6, 91.8
Chironomus kiiensis	Diptera	Stream	7.2	3.88, 322, 574, 1051, 1910, 3499
Brachionus calyciflorus	Rotifera	Stream	7.7	0.100, 14.1, 29.1, 67.8, 151, 238, 498
Branchinella kugenumaensis	Amphipoda	Stream	7.6	0.0259, 20.0, 42.5, 86.0, 184, 369

1. Introduction

Ammonia was included in the second Priority Substances List pursuant to the Canadian Environmental Protection Act, 1999 (Minister's Expert Advisory Panel 1995) due to the concerns about its harmful effects on organisms exposed to significant levels of ammonia released from various anthropogenic and natural sources (Constable et al., 2003). The anthropogenic sources of ammonia in the aquatic environment include municipal effluent discharges and agricultural runoff and the natural sources include nitrogen fixation and the excretion of nitrogenous waste from animals (US EPA, 2013).

The chemical form of ammonia in water comprises two species, the more abundant one is the ammonium ion (NH_4^+) and the less abundant one is the non-dissociated or unionized ion molecule (NH_3). The ratio of these species in a given aqueous solution depends on both pH and the temperature of the water; as pH and temperature increase, the concentration of NH_3 also increases but the concentration of NH_4^+ decreases (Emerson et al., 1975). The concentration of total ammonia is the sum of NH_4^+ and NH_3 concentrations (US EPA, 2013). The ionized ammonium ion and unionized ammonia molecule are interrelated through the chemical equilibrium between NH_4^+ and NH_3 (Emerson et al., 1975). The unionized ammonia is very toxic to aquatic life, particularly to fish, whereas ionized ammonia is nontoxic or significantly less toxic (Russo, 1985; Environment Canada, 2001).

Toxic effects of ammonia on aquatic life have been extensively studied. In fish, for example, ammonia can cause proliferation in gill tissues, increase ventilation rates, damage the gill epithelium (Lang et al., 1987), reduce blood oxygen-carrying capacity due to progressive acidosis

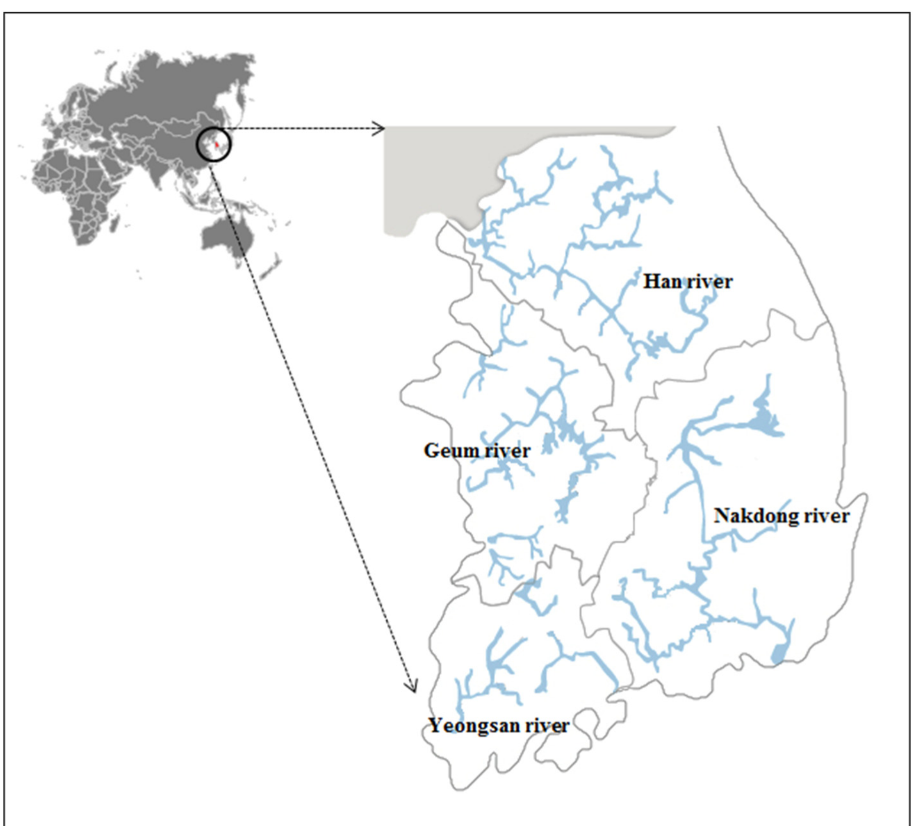

Fig. 1. Map of four major river basins in Korea, in which there are 905 monitoring stations nationwide.