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Effects of unionised ammonia on tropical freshwater organisms: Implications on temperate-to-tropic extrapolation and water quality guidelines

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ABSTRACT

Unionised ammonia (NH_3) is highly toxic to freshwater organisms. Yet, most of the available toxicity data on NH_3 were predominantly generated from temperate regions, while toxicity data on NH_3 derived from tropical species were limited. To address this issue, we first conducted standard acute toxicity tests on NH_3 using ten tropical freshwater species. Subsequently, we constructed a tropical species sensitivity distribution (SSD) using these newly generated toxicity data and available tropical toxicity data of NH_3, which was then compared with the corresponding temperate SSD constructed from documented temperate acute toxicity data. Our results showed that tropical species were generally more sensitive to NH_3 than their temperate counterparts. Based on the ratio between temperate and tropical hazardous concentration 10% values, we recommend an extrapolation factor of four to be applied when surrogate temperate toxicity data or temperate water quality guidelines of NH_3 are used for protecting tropical freshwater ecosystems.

1. Introduction

Ammonia is considered as one of the most important pollutants in the freshwater environment. It can enter natural aquatic systems through direct means such as municipal sewage effluent discharges and excretion of nitrogenous wastes from animals, and indirect means such as natural nitrogenous organic matter breakdown in contaminated sediments (Thurston and Russo, 1986). In freshwater aqueous solution, unionised ammonia (NH_3) exists in an equilibrium with ionised ammonia (NH_4^+), in which the concentration of NH_3 is positively correlated with water temperature and pH (Emerson et al., 1975). Harmful effects of ammonia on aquatic organisms have been extensively studied. In fish, for instance, ammonia can disrupt the normal functions of internal organs such as damage to the gill epithelium (Lang et al., 1987) and disruption of normal metabolic functioning of the liver and kidneys (Arillo et al., 1981).

To better control the release of ammonia and protect freshwater organisms from the toxicity of ammonia, a number of guidelines or criteria for ammonia have been established around the globe (Table 1). For example, Australian and New Zealand governments jointly recommended water quality guideline (WQG) of 30 μg L^{-1} NH_3 at pH 8.0 (warm-water) for protecting 95% of freshwater species (ANZECC & ARMCANZ, 2000). Canada recommended a comparatively lower WQG value for NH_3 at 19 μg L^{-1} NH_3 which was derived from chronic toxicity data (CCME, 2010). The Environment Protection Agency of the United States (US EPA) set a more stringent chronic water quality criterion at 1.9 mg L^{-1} Total Ammonia Nitrogen (TAN; = 9.1 μg L^{-1} NH_3) at pH 7.0 and 20 °C, while its acute criterion was as high as 17 mg L^{-1} TAN (= 81 μg L^{-1} NH_3) (US EPA, 2013). Nonetheless, the guidelines for ammonia in tropical regions are more lacking, except that South Africa recommended acute and chronic WQGs at 100 μg L^{-1} NH_3 and 15 μg L^{-1} NH_3, respectively (DWAF, 1996), Hong Kong set up the standard of 2 mg L^{-1} TAN at 30 °C (HKEPD, 1997), and Malaysia required a more stringent criteria of 0.3 mg L^{-1} TAN (Department of Environment Malaysia, 1985) for protecting freshwater ecosystems.

To date, most of the documented acute toxicity test results for ammonia were primarily generated from temperate species in North America and Europe (Kwok et al., 2007). Acute toxicity data on ammonia derived from tropical species are limited except for two taxonomic groups of species namely, amphibians and fishes. Most tropical WQGs and ecological risk assessment (ERA) studies

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Table 1
Summary of current freshwater ammonia water quality guidelines (WQGs). All WQGs in terms of unionised ammonia (NH_3) concentrations are expressed as NH_3 form. Bold letter for each WQG represents the value collated or calculated from the original reports/documents at pH 7.0 and 20 °C for temperate and pH 7.0 and 25 °C for tropics (except Australia and New Zealand at pH 8.0 and Hong Kong at 30 °C). NA indicates that data are not available.

Country/Region	Water quality guideline (WQG)			Trigger values	*n*	Source
	Acute/Chronic	NH_3 (μg L^{-1})	Total Ammonia Nitrogen (TAN; mg L^{-1})			
Australia and New Zealand	Chronic	**20** (pH > 8.0 and cold-water)	NA	HC5: 900 μg L^{-1} TAN	44	(ANZECC & ARMCANZ, 2000)
		30 (pH 8.0 and warm-water)	NA			
Canada	Chronic	**19**	**3.96**	Lower-hand of HC5: 19 μg L^{-1} NH_3	13	(CCME, 2010)
British Columbia, Canada	Acute	92[a]	**19.2**	NA	NA	(Nordin and Pommen, 2009)
	Chronic	5.9[a]	**1.22**	NA	NA	
Ontario, Canada	Chronic	**20**	42[b]	NA	NA	(Ontario Ministry of the Environment, 1994)
China	Chronic	**20**	42[b]	NA	NA	(State Environmental Protection Administration, 1989)
European Union	Chronic	0.96[a]	**0.2** (stringent)	NA	NA	(EU, 2006)
		4.8[a]	**1.0** (imperative)	NA	NA	
England and Wales, UK	Chronic	1.2[a]	**0.25** (high status)	NA	NA	(Water Framework Directive, 2008)
	Chronic	2.9[a]	**0.6** (good status)	NA	NA	
Limerick, Ireland	Chronic	**20**	42[b]	NA	NA	(Abattoirs Act, 1988)
US EPA	Acute	81[a]	**17**	FAV[d]: 33.52 mg L^{-1} TAN	69	(US EPA, 2013)
	Chronic	9.1[a]	**1.9**	FCV[d]: 1.887 mg L^{-1} TAN	16	
Connecticut, US	Acute (1 h)	**115**[c] (salmonids present)	24[b]	NA	NA	(Connecticut Department of Environmental Protection, 2011)
	Chronic (30 d)	**20**[c] (fish early life stages present)	4.1[b]	NA	NA	
	Chronic (4 d)	**50**[c]	10.3[b]	NA	NA	
Illinois, US	Acute	72[a]	**15**	NA	NA	(Illinois Environmental Protection Agency, 2002)
	Chronic	20[a]	**4.15** (fish early life stages present)	NA	NA	
Indiana, US	Acute	**93**	19.3	NA	NA	(Indiana Government, 1996)
Minnesota, US	Chronic	**16** (cold-water)	3.4[b]	NA	NA	(Minnesota Pollution Control Agency, 2008)
		40 (cool- and warm-water)	8.4[b]			
New York, US	Acute	**93**	**23**	NA	NA	(New York State Department of Environmental Conservation, 1996)
	Chronic	**8.3**	**2.1**	NA	NA	
Ohio, US	Acute	62[a]	**13**	NA	NA	(Ohio Environmental Protection Agency, 2014)
	Chronic	28[a]	**5.9** (warm-water; December to February)	NA	NA	
		15[a]	**3.2** (warm-water; March to November)	NA	NA	
		7.2[a]	**1.5** (cold-water)	NA	NA	
Oregon, US	Acute (1 h)	93[a]	**19.5**[c]	NA	NA	(Oregon Department of Environmental Quality, 2014)
	Chronic (4 d)	8.3[a]	**1.8**[c]	NA	NA	
Wisconsin, US	Acute	115[a]	**24.1**	NA	NA	(Wisconsin Department of Natural Resources, 2004)
South Africa	Acute	**100**	17.9[b]	NA	NA	(DWAF, 1996)
	Chronic	**15**	2.7[b]	NA	NA	
Malaysia	Chronic	2.1[a]	**0.3**	NA	NA	(Department of Environment Malaysia, 1985)
Hong Kong	Chronic	20[a]	**2** (at 30 °C)	NA	NA	(HKEPD, 1997)

[a] Original standard in TAN, transformed to NH_3 at pH 7.0 and 20 °C for temperate and pH 7.0 and 25 °C for tropics.
[b] Original standard in NH_3, transformed to TAN at pH 7.0 and 20 °C for temperate and pH 7.0 and 25 °C for tropics.
[c] Original standard in pH- and temperature-dependent equations, NH_3 at pH 7.0 and 20 °C was calculated.
[d] FAV: Final Acute Value; FCV: Final Chronic Value.