Development of an Integrated Environmental Impact Assessment Model for Assessing Nitrogen Emissions from Wastewater Treatment Plants

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Background and objective

Background

Environmental impact assessments for wastewater treatment plants (WWTPs) have evaluated many endpoints including emissions of greenhouse gases, discharges of nutrients and discharges of toxic substances in context of life cycle assessment (LCA). However, ecotoxicity of discharge not well treated in existing research.

Objective

- Develop an integrated environmental impact assessment model for wastewater treatment processes, especially concerned to **evaluate the ecotoxicity impact of NH_4-N by introducing it into an existing LCA model.**
- **Apply the model developed to an actual WWTP** operating under two different conditions and evaluate the best operating conditions based on nitrogen emissions by nitrification.

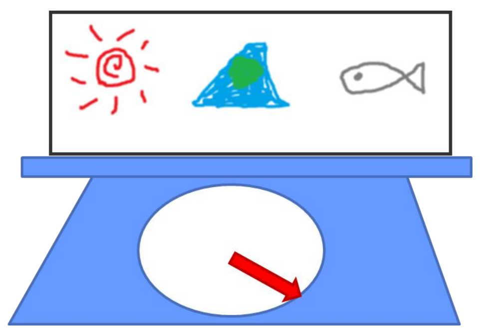

Fig. 0: “Integrated environmental impact assessment”

Methodology

Assessment of WWTP using a LCA model

Environmental impact of the WWTP is assessed using LIME2, Japanese Life cycle impact assessment model. Environmental loads shown in Fig. 1 is assessed in this study. Pollutants and substances cause environmental problem (Midpoint) and damage human, ecosystem, and social assets (Endpoint). We newly developed. This study impacts to the endpoints are converted economic value to enable compare total impact on environment.

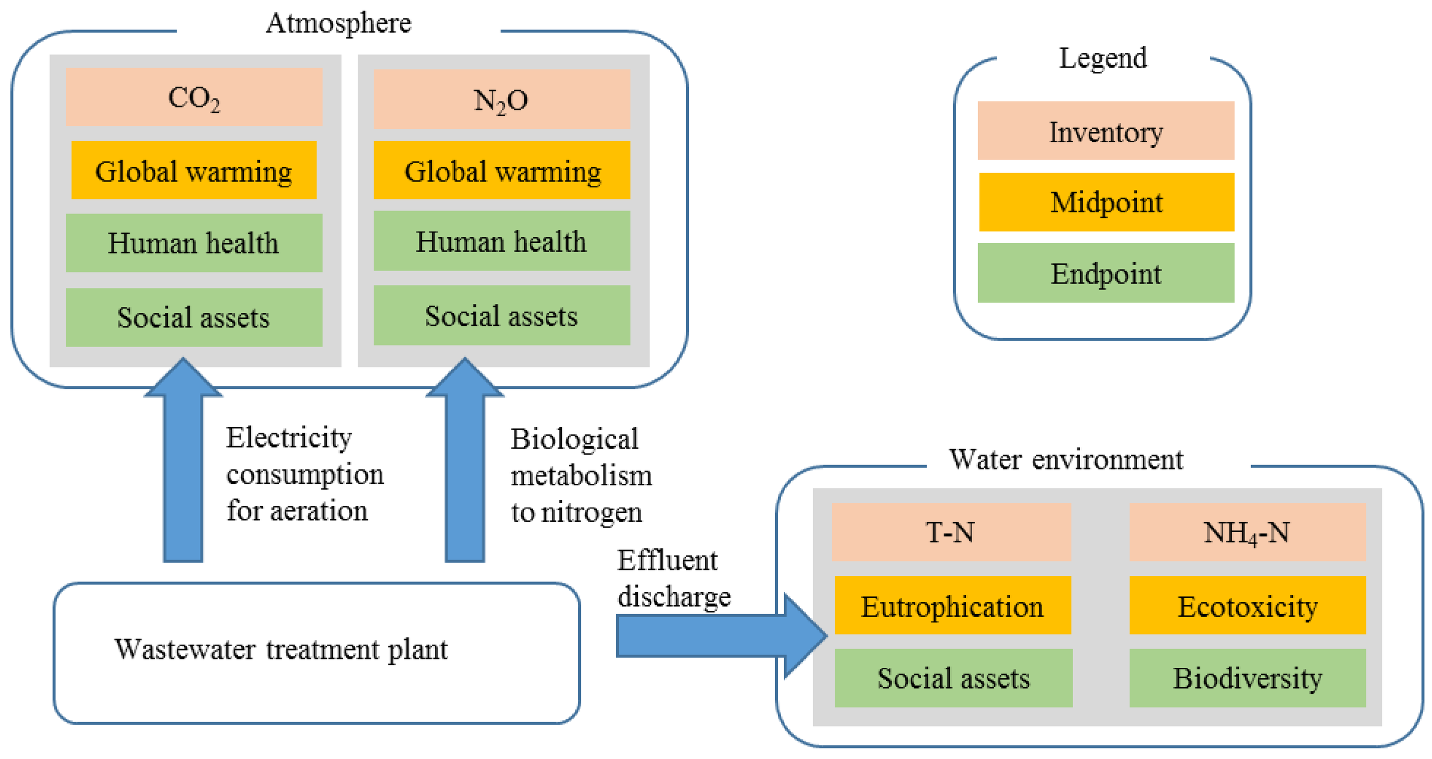

Fig. 1: System boundaries for assessment of WWTP

Development of ecotoxicity impact evaluation

Method for evaluating environmental impact of NH4-N on biodiversity is newly developed in this study. The model(Fig. 2) estimates expected value of species extinction. This model includes equation calculating the ratio of NH_3 in NH_4-N from pH and temperature (1), relationship between density of pollutant and expected number of species extinction (2), calculation of NH_3 concentration increase per unit NH_4-N emission, and conversion impacts on each endpoint to economic value.

Table 1: Equations in the ecotoxicity estimation model

Process in Figure 2	Equation
(1)	$r_{NH3} = f(\text{pH, temp})$
(2)	$DF_{NH3\text{-}N} = \sum_i \sum_j D_j(LC50_i, [NH_3\text{-}N]) \cdot N_{i,j}$
(3)	$DF_{NH4\text{-}N} = DF_{NH3} \cdot r_{NH3} / wr \cdot p \cdot 10^3$
(4)	$EI = DF_{NH4\text{-}N} \cdot e_{NH4\text{-}N} \cdot WF$

rNH_3-N: the ratio of NH_3 in NH_4-N calculated from pH and temperature (temp).
$DF_{NH3\text{-}N}$: damage factor of increasing NH_3-N concentration.
EINES: unit of expected increase in numbers of species extinct.
D_j: the marginal increase in expected percentage of extinction in rank j species following increase in NH_3-N concentration.
$LC50_i$: an index of ecotoxicity. N(i,j: the number of species group i (fish and crustaceans) and rank at threat of extinction j.
$DF_{NH4\text{-}N}$ is the damage factor of NH_4-N emissions
wr: the renewable water resource in Japan.
p is the NH_4-N decrease factor in environmental water following nitrification
EI is the impact of ecotoxicity on biodiversity from NH4-N discharge;
eNH4-N: the amount of NH4-N emissions, WF: the weighting factor.

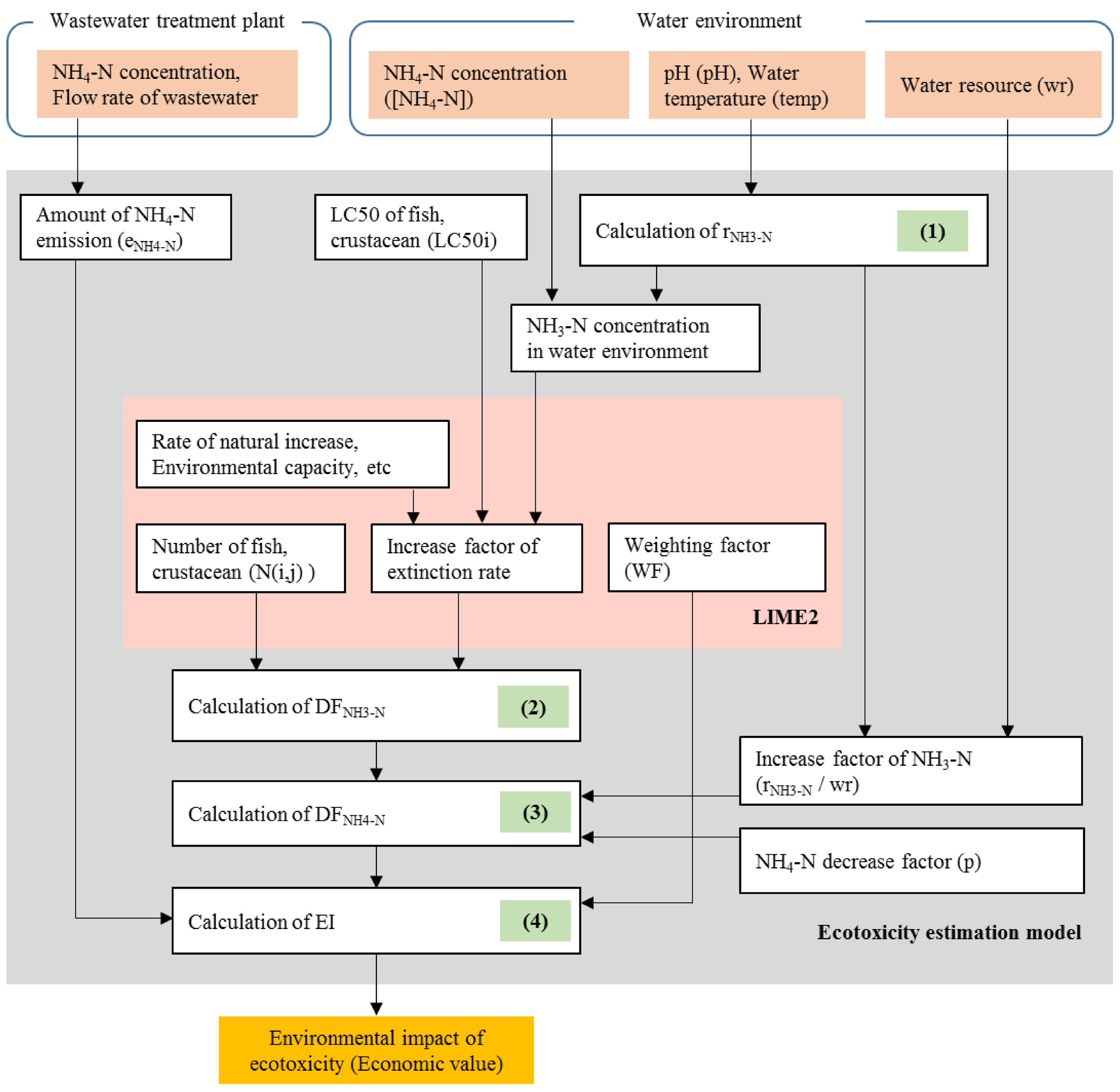

Fig. 2: Calculation flow in the ecotoxicity estimation model

Results and discussion

Estimation of damage factor

To estimate damage factor ($DF_{NH4\text{-}N}$ in equation(2)) data of environmental water in Saitama Pref., Japan is obtained. The WWTP is operated by the conventional activated sludge process with continuous aeration under two operating conditions (case 1 and case 2) . The wastewater was treated with less aeration in case 1, to save electricity consumption, without nitrification. In case 2 nitrification was accelerated with a large rate of aeration.

Table: Data obtained in the water environment and WWTP

Parameter	Units	Data Case1	Data Case2	Midpoints	Data source
Water environment					
pH		7.6		Ecotoxicity	Water quality measurement result at public water bodies, Saitama pref.
Water temperature	℃	17		Ecotoxicity	Water quality measurement result at public water bodies, Saitama pref.
NH_4-N concentraion ($[NH_4\text{-}N]$)	mgN/L	0.31		Ecotoxicity	Water quality measurement result at public water bodies, Saitama pref.
Water resource (W^r)	m^3	4.1E+11		Ecotoxicity	Water resource of Japan, MLIT
Wastewater treatment plant					
N_2O emission from WWTP	kgN_2O/d	1.2	2.9	Global warming	Actual measurement
NH_4-N concentraion in effluent	mgN/L	9.9	1.1	Ecotoxicity	Actual measurement
T-N concentration in effluent	mgN/L	17	11	Eutrophication	Actual measurement
Electricity consumption for aeration	kWh/d	2400	3000	Global warming	Operating data from WWTP monitoring reports
Flowrate of wastewater	m^3/d	24000		Eutrophication, Ecotoxicity	Operating data from WWTP monitoring reports

$DF_{NH4\text{-}N}$ was estimated to 1.93×10^{-11} EINES/kgN. This result meant that **NH_4-N had almost the same ecotoxicity as toluene** (2.11×10^{-11}) **or pyrocatechol** (1.95×10^{-11}) in the water environment. The estimated value is sensitive to changes of some parameters (Fig. 3). **pH seems to be the most important and sensitive** component of the damage factor, when considering the slope of the curve and available range, the 75% and 25% value of observations. In contrast, NH_4-N concentrations of environmental water had little effect on the damage factor.

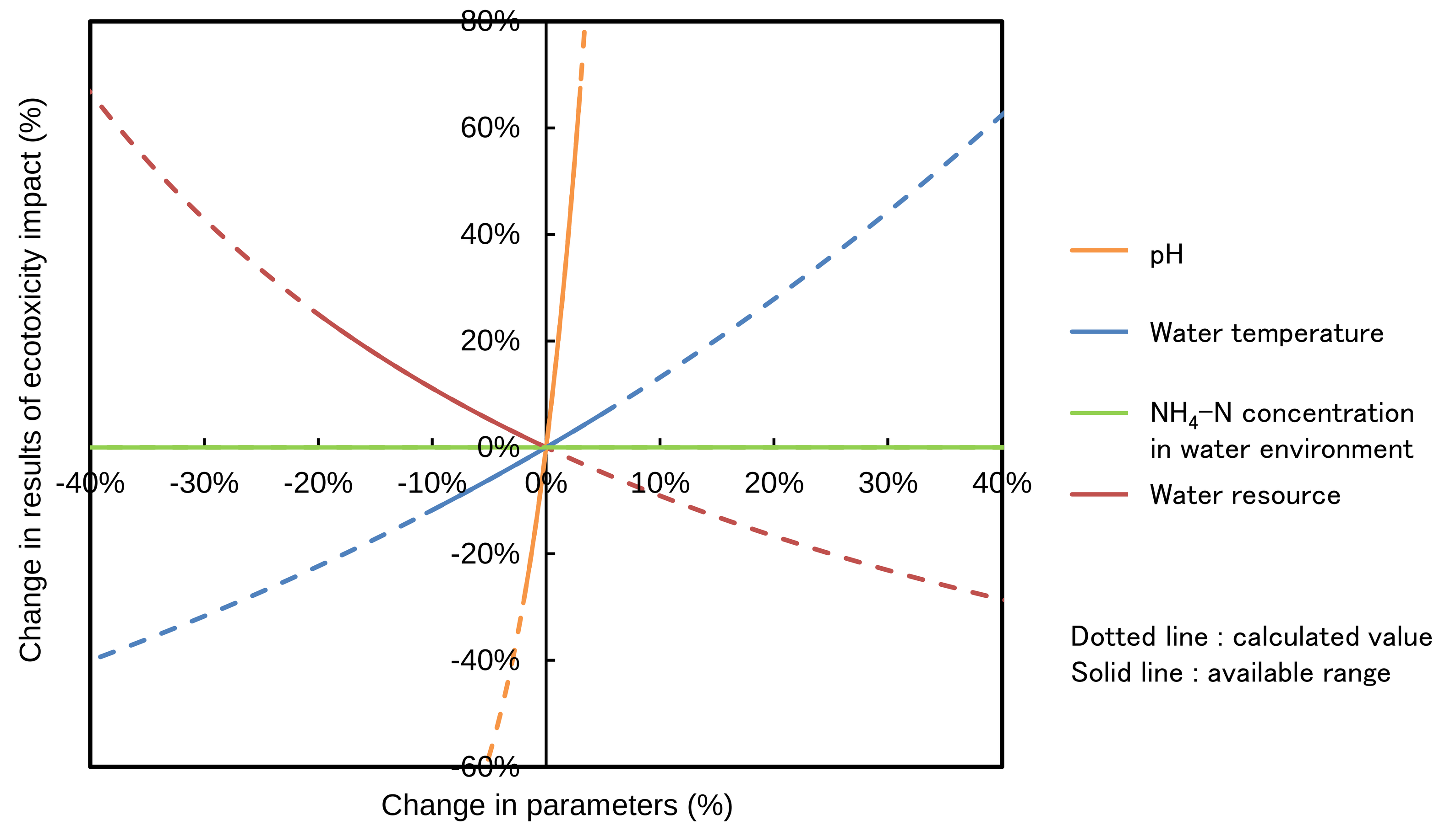

Fig. 3: Sensitivity analysis of damage factor

Integrated environmental impact assessment from WWTP

The results in Fig. 4 show that the main contributor to the environmental impacts from WWTP in case 1 was ecotoxicity due to discharges of NH_4-N. The impacts of ecotoxicity in cases 1 and 2 were estimated to be 2.7 and 0.3 yen/m^3, respectively. Because NH_4-N concentration was decreased by nitrification in case 2, the impacts of ecotoxicity also decreased. The impact for global warming due to the discharge of CO_2 and N_2O was lower than the other impacts in both cases. It was suggested that the **cost of NH_4-N ecotoxicity was about 6.4% of the total wastewater treatment cost**.

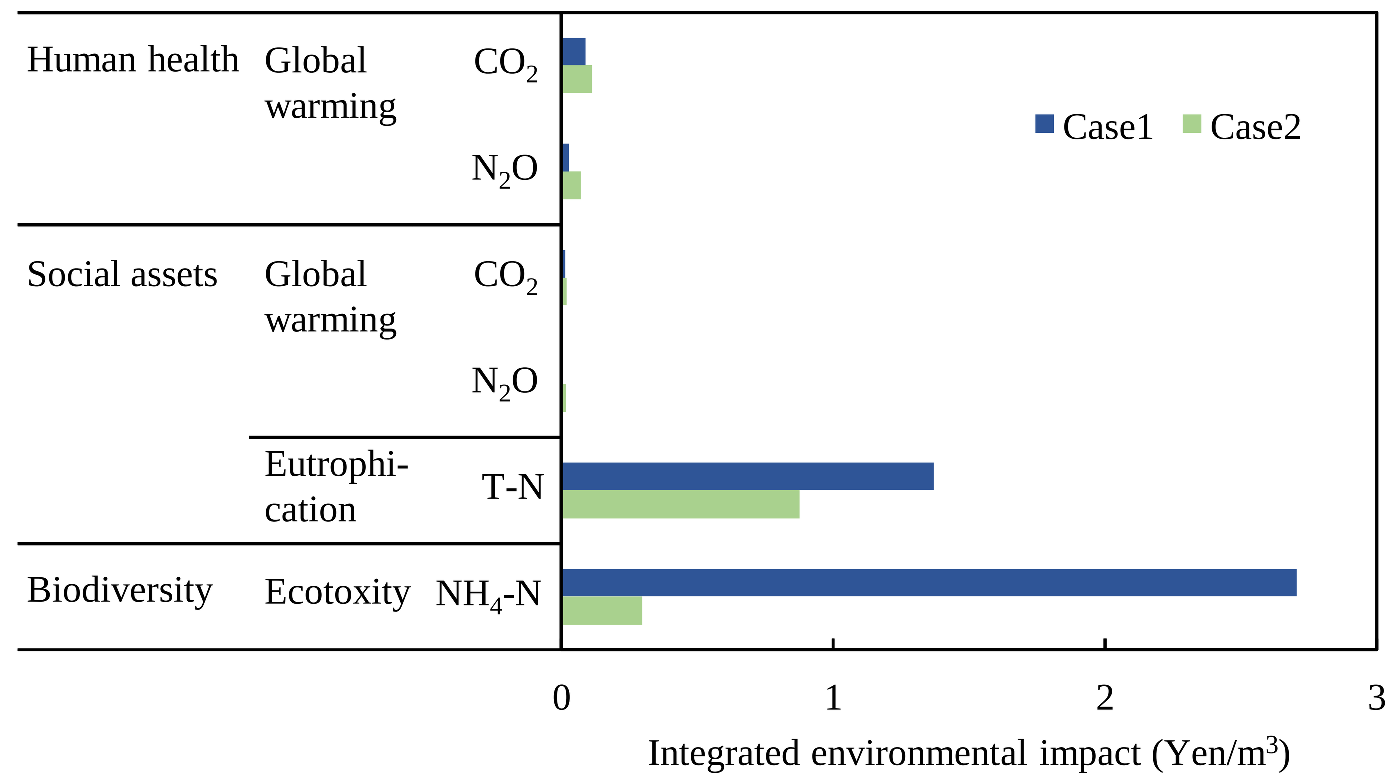

Fig. 4: Estimated results of the integrated environmental impacts

Conclusion

- This study developed methodology to evaluate Influence of NH_4-N ecotoxicity in the context of LCA
- Ecotoxicity of NH_4-N is most sensitive to pH in Environmental water
- In LCA of WWTP, NH_4-N may be main contributor to total environmental impact depending on operation condition