Critical load of soil acidification and surface water eutrophication in EANET participating countries

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What is a critical load ?

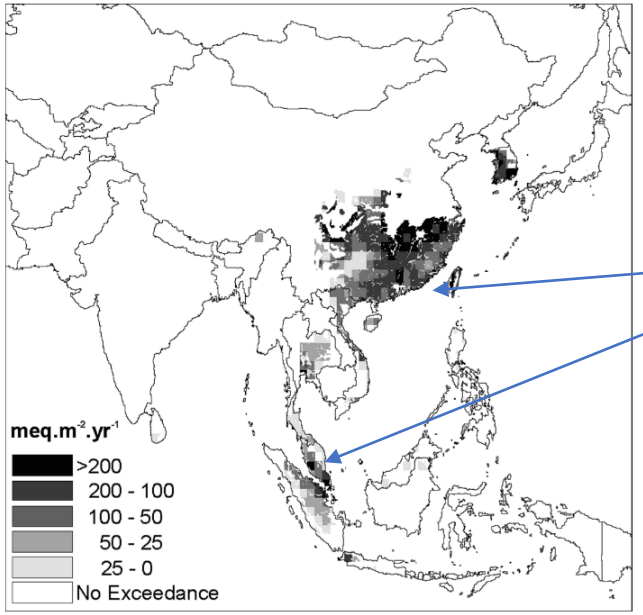
- The “critical load” model is a quantitative approach to ecological risks based on a steady-state mass balance model (Sverdrup and Devries, 1994) and uses a **threshold indicator to evaluate** (for example) **soil and surface water acidification and eutrophication** as causes of forest degradation or imbalances in nutrient cycles.

- The critical loads of N, which are the limiting factors for eutrophication including the problem of increased N leaching in forests in case of eutrophication, are widely accepted (e.g., Reinds et al., 2008; Saros et al., 2010).

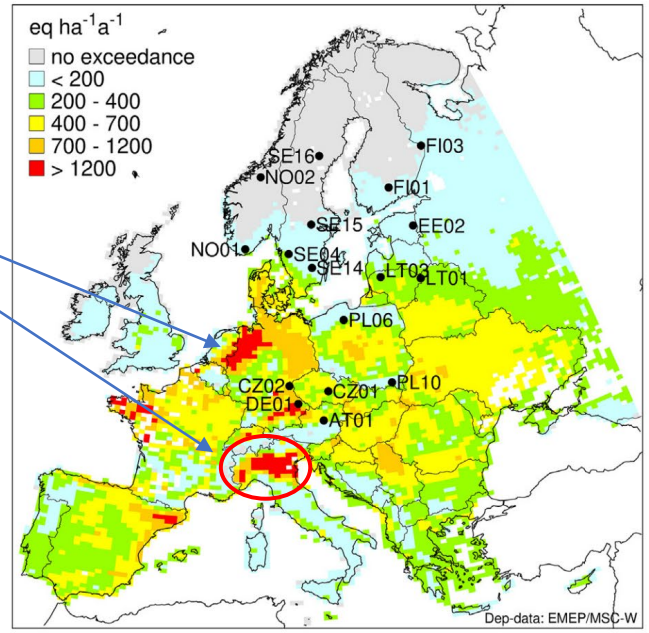
Critical load exceedance

- **Critical load exceedance = atmospheric deposition – critical load**
- Critical load exceedance >> 0 : high risk for ecosystem
- Critical load exceedance << 0 : low risk for ecosystem
- Each value should spatially differ within the target area (East and Southeast Asia); thus, we have predicted and mapped them using the GIS approach, available or simulated spatial data.

In contrast to Europe, critical load exceedance maps, including East and Southeast Asia, have yet to be published in recent years (ex-China)



High risk!



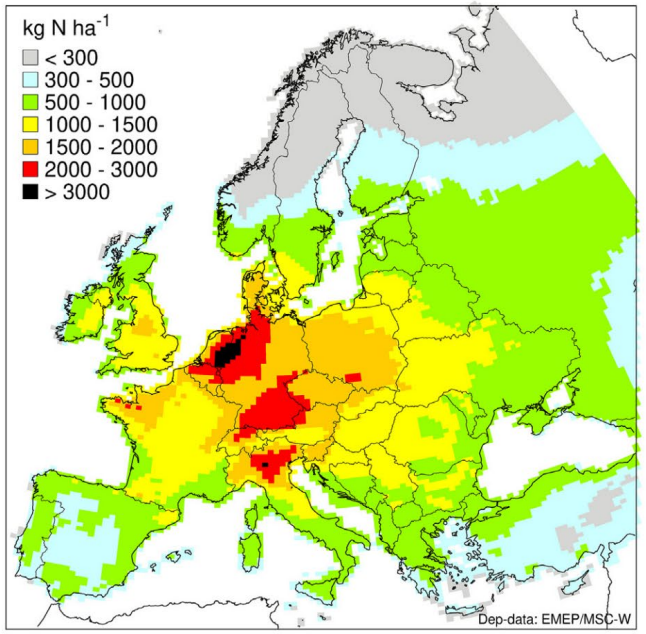
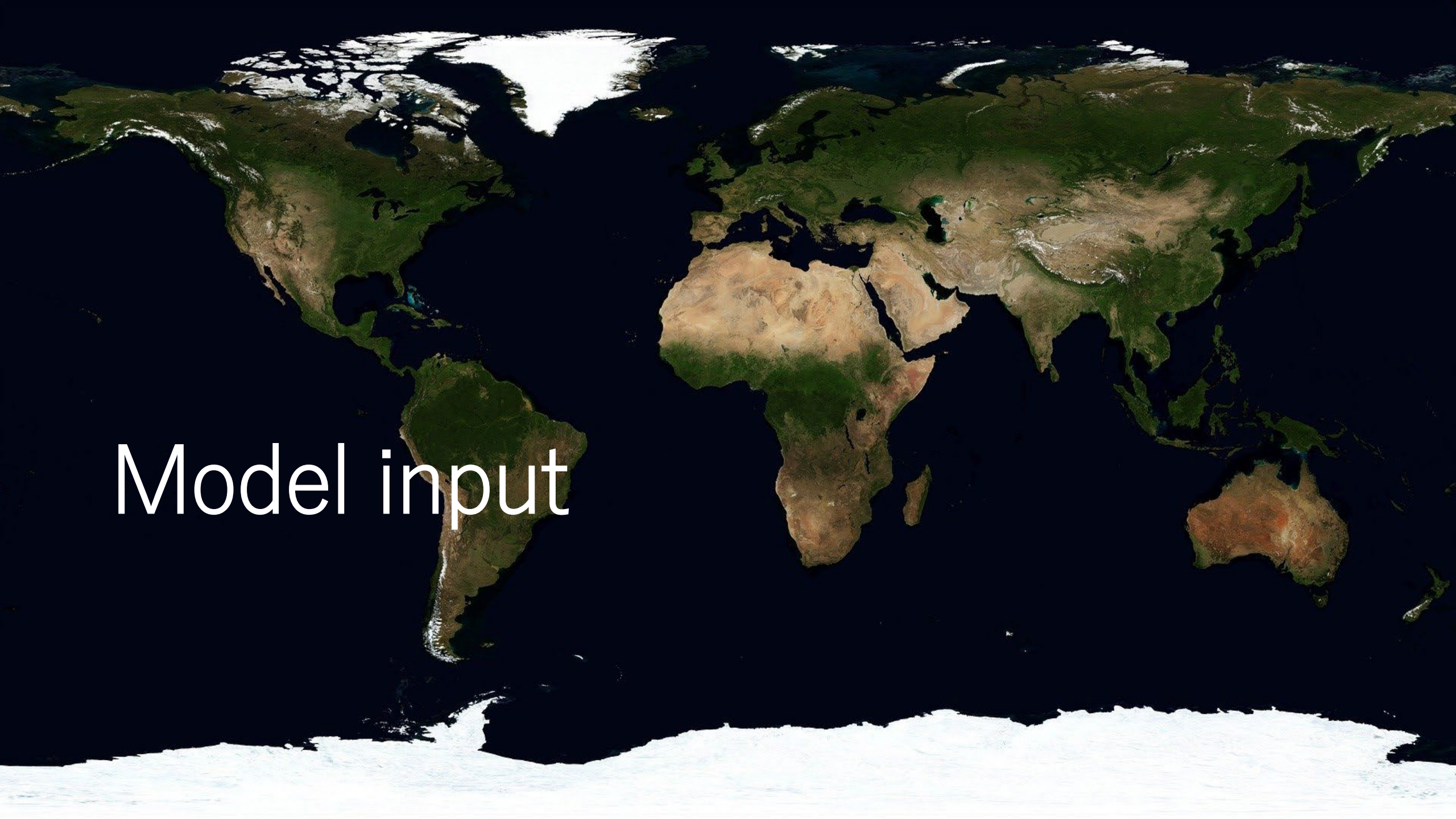


Figure 4. Map of exceedance of critical loads in 2025 using high BC_{dep} and high CL range (see Table I) and the low emission scenario (convergence of emission control technology in developing Asian countries to 1995 average levels for OECD countries by the year 2025).

(Kuylenstierna et al., 2001)

Fig. 1. Locations of the 17 ICP IM sites considered in this paper (left). On the background map the 2015 average accumulated exceedance (AAE, in eq ha^{-1} yr^{-1}) of the European critical loads of eutrophication is shown. Right: The modelled cumulative deposition of total nitrogen ($NO_x + NH_3$) for the period 1880–2020 in Europe.

(Forsius et al., 2021)


Model input

Input values: Critical load for soil acidification

(Unit: eq/ha/year)

$$CL_{max}S = BC_{dep} - Cl_{dep} + BC_{w} - Bc_{u} + ANC_{le,crit}$$

$$CL_{max}N = CL_{min}N + CL_{max}S/(1 - f_{de})$$

$$CL_{min}N = N_i + N_u$$

$$ANC_{le,crit} = Q \cdot ([H]_{crit} + K_{gibb.}\,[H]^3_{crit})$$

$$[H]_{crit} = \begin{cases} 0.1 \; if \; ([H]_i \leq 0.1) \\ [H]_i \times 1.1 \; if \; ([H]_i > 0.1) \end{cases}$$

Soil pH 4.0

harmful level to plant roots

$CL_{max}S$: critical load of S deposition
$CL_{max}N$: critical load of N deposition

dep: deposition rate
w: weathering rate
u: plant uptake (by harvesting)
i: immobilization
f_{de}: denitrification constant
K_{gibb}: gibbsite equilibrium constant

BC: base cations
ANC: acid neutralization capacity
Q: water discharge
$[H]_{crit}$: acceptable criterion for soil pH

Input values: Critical load for eutrophication

$$\mathrm{CL}_{nut}(N) = \begin{cases} N_i + N_u + \frac{N_{le(acc)}}{1-f_{de}} \; if \; N_{dep} > N_i + N_u \\ N_i + N_u + N_{le(acc)} \; else \end{cases}$$

(Unit: eq/ha/year)

$$N_{le(acc)} = \mathrm{Q} \cdot [\mathrm{N}]_{acc}$$

Acceptable nitrate values

$$[\mathrm{N}]_{\mathrm{le.acc}} = 0.3 \text{ mg } \mathrm{L}^{-1}$$

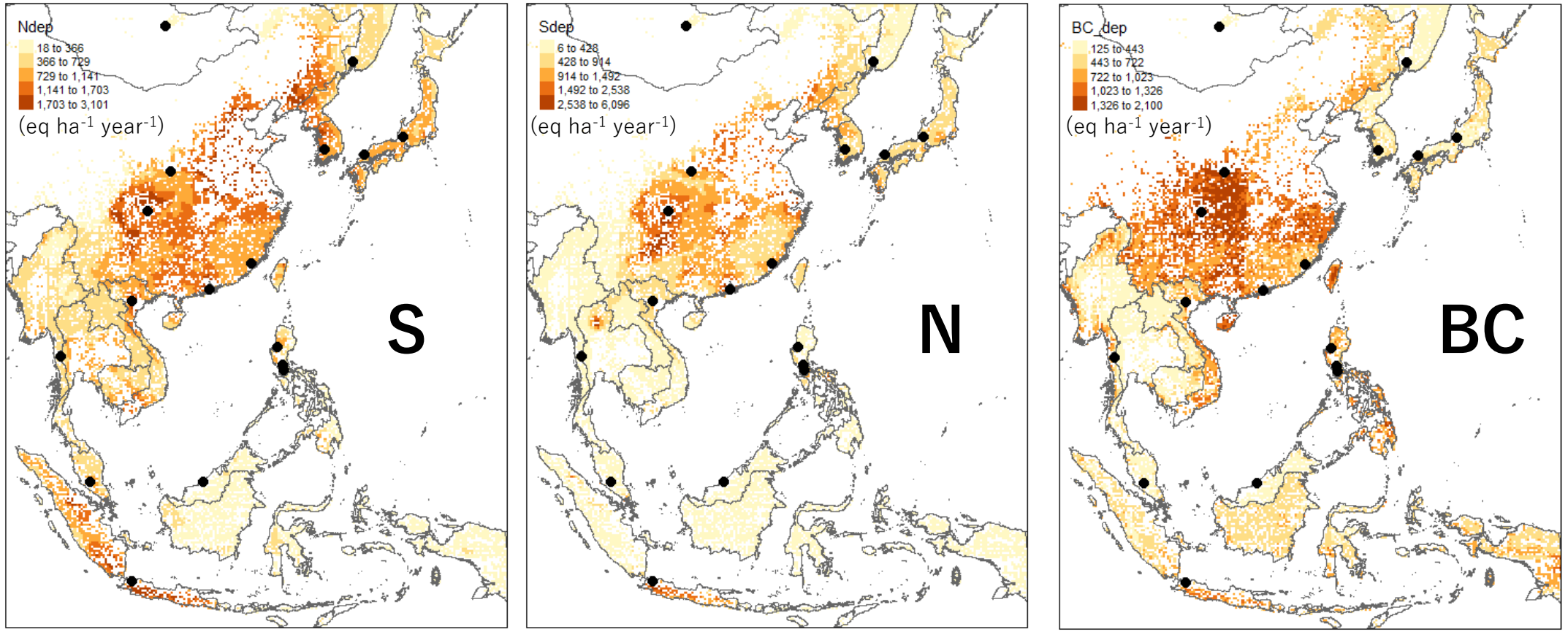
criterion for nutrient imbalances in forest ecosystems (CRATAP 2005)

$CL_{nut}N$: critical load of N deposition for eutrophication

dep: deposition rate
u: plant uptake (by harvesting)
i: immobilization
f_{de}: denitrification constant

Q: water discharge
$N_{le(acc)}$: acceptable value for nitrate concentration

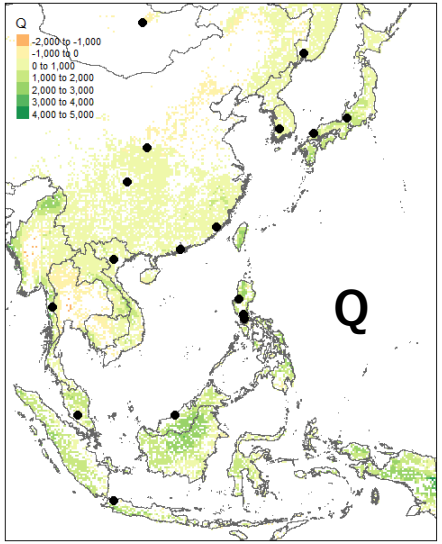
Simulation of the depositions (S_{dep}, N_{dep}, BC_{dep})

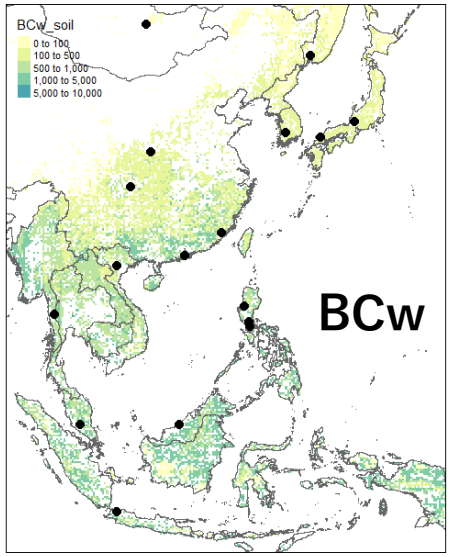


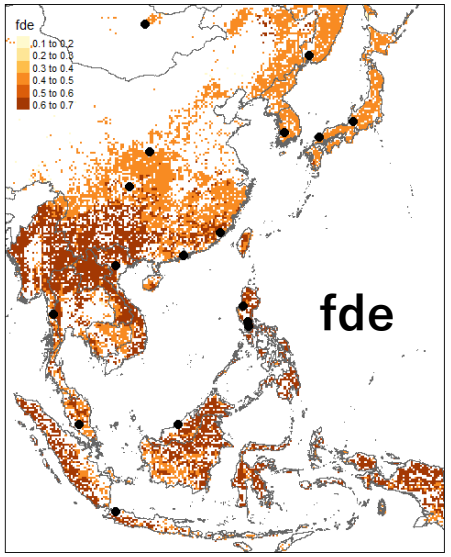
Atmospheric chemical transport model: CMAQ ver.5.02 + WRF3.5.1
Emission inventory: MIX, Li et al., 2017
Spatial resolution: *ca.* 45 km

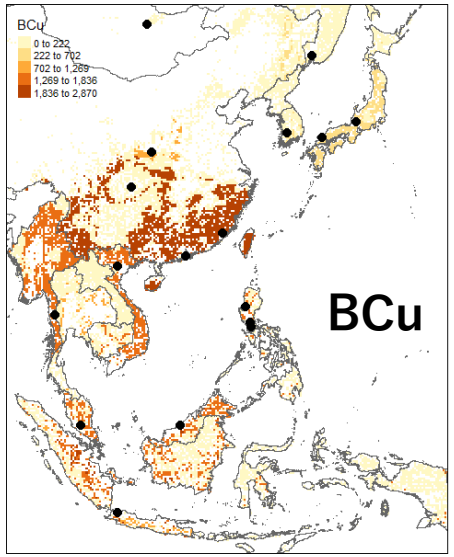
Machine learning model (random forest)
Objective data: monthly data of EANET monitoring (54 sites)
Explanatory data：precipitation, temperature, position, population, country border, and so on
R^2: 0.21 – 0.35

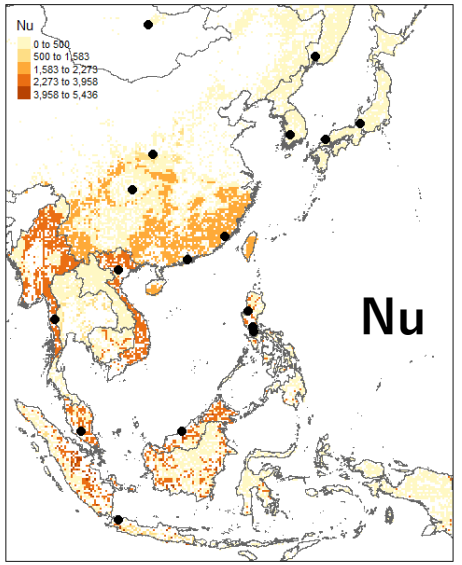
Estimation of the input values (Q, BCw, fde, Bcu, Nu,)











calculated by thornthwaite model using WorldClim ver. 2.1 (Fick and Hijmans, 2017)

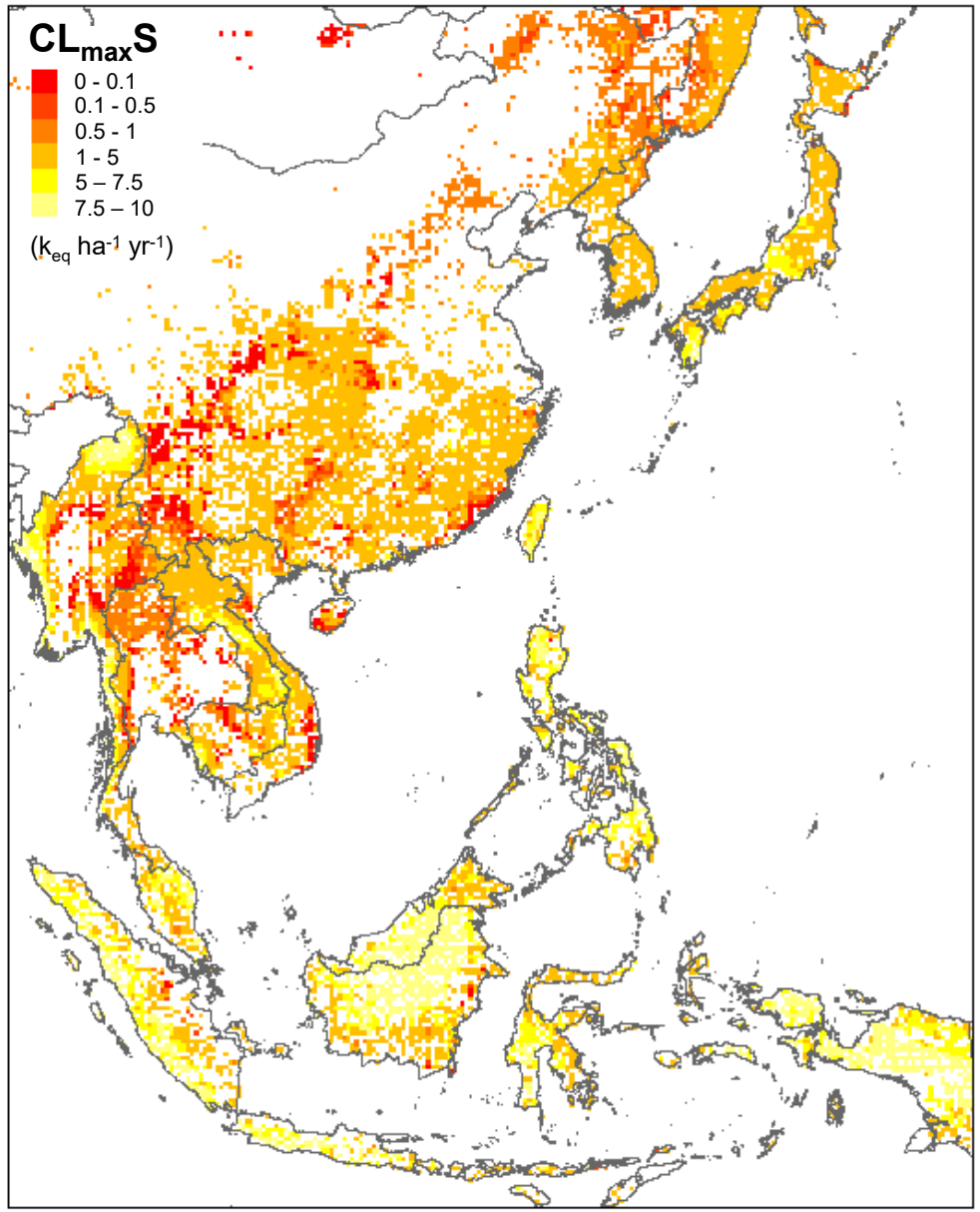
calculated by PROFILE model using Global soil mineral data (Ito and Wagai 2017)

assumed to be affected by soil Clay contents referred from the "open land map." (https://openlandmap.org/)

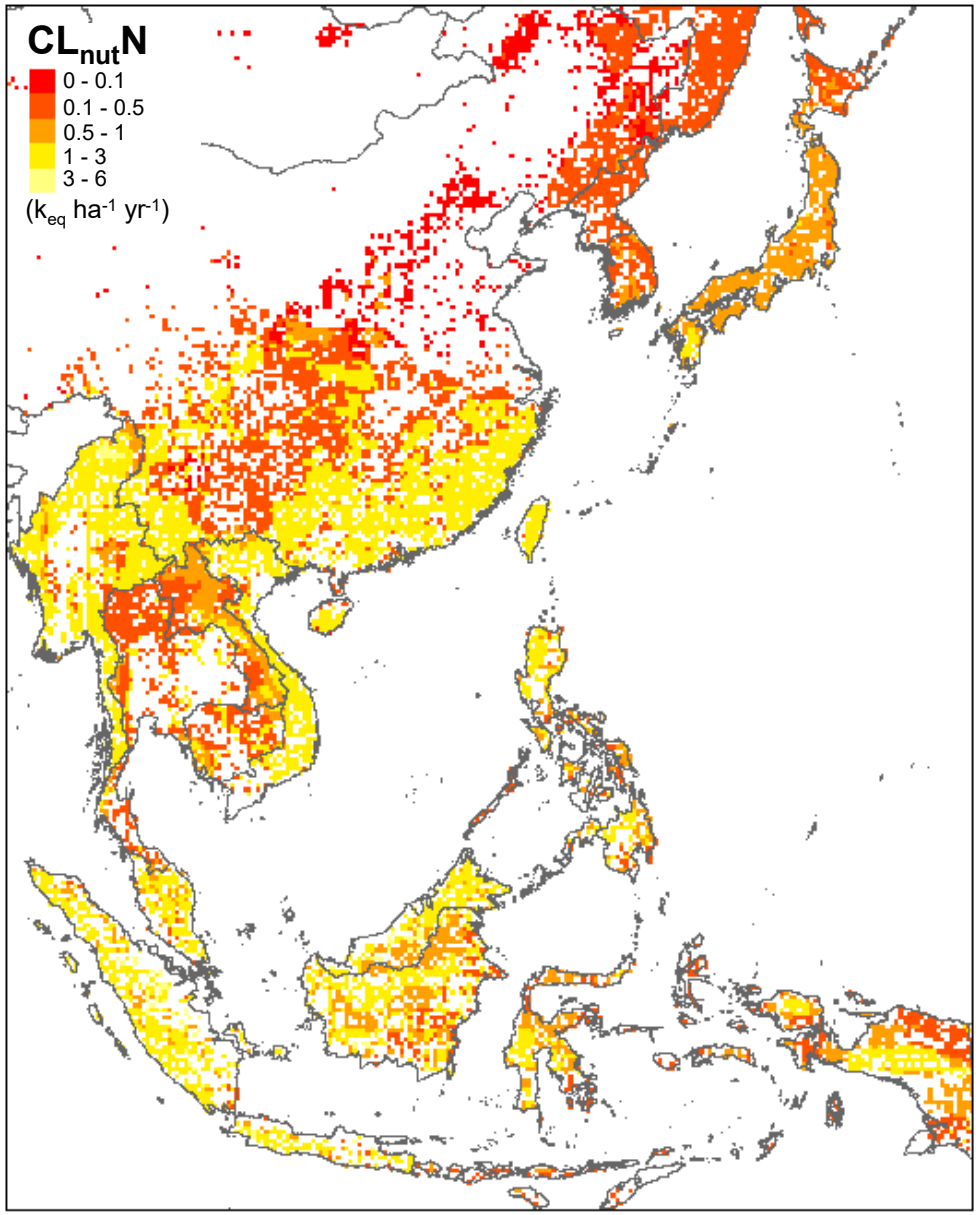
Cambodia, Indonesia, Japan, Laos, Malaysia, Myanmar, Philippines, South Korea, and Thailand: Spatial Database of Planted Trees compiled by Global Forest Watch (SDPT ver. 1.0, Harris et al., 2019)
China: Duan et al., 2004
Mongolia, North Korea, and Russia: assumed to be zero

Mapping critical load and exceedances and the verification

Critical load for soil acidification

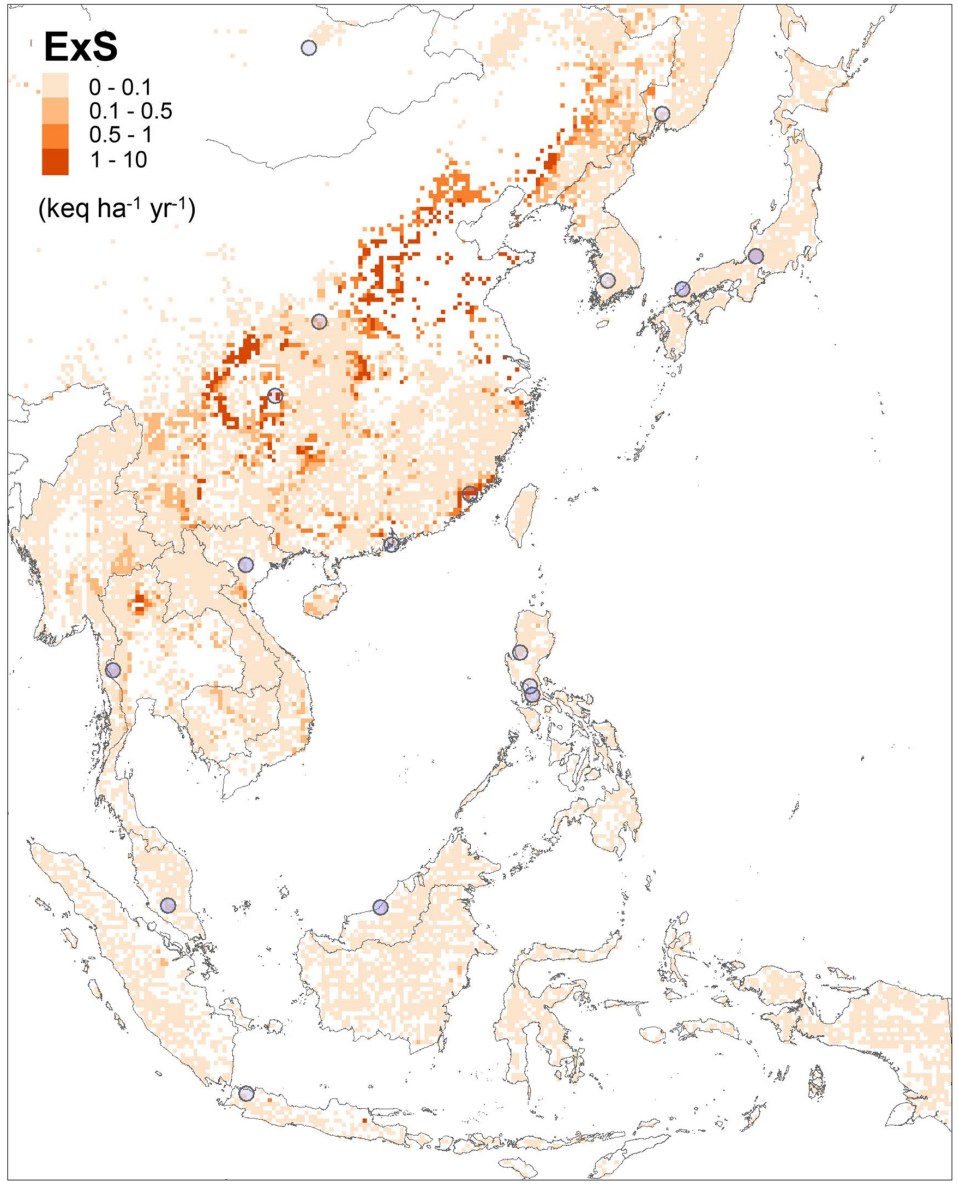


Critical load for surface water eutrophication

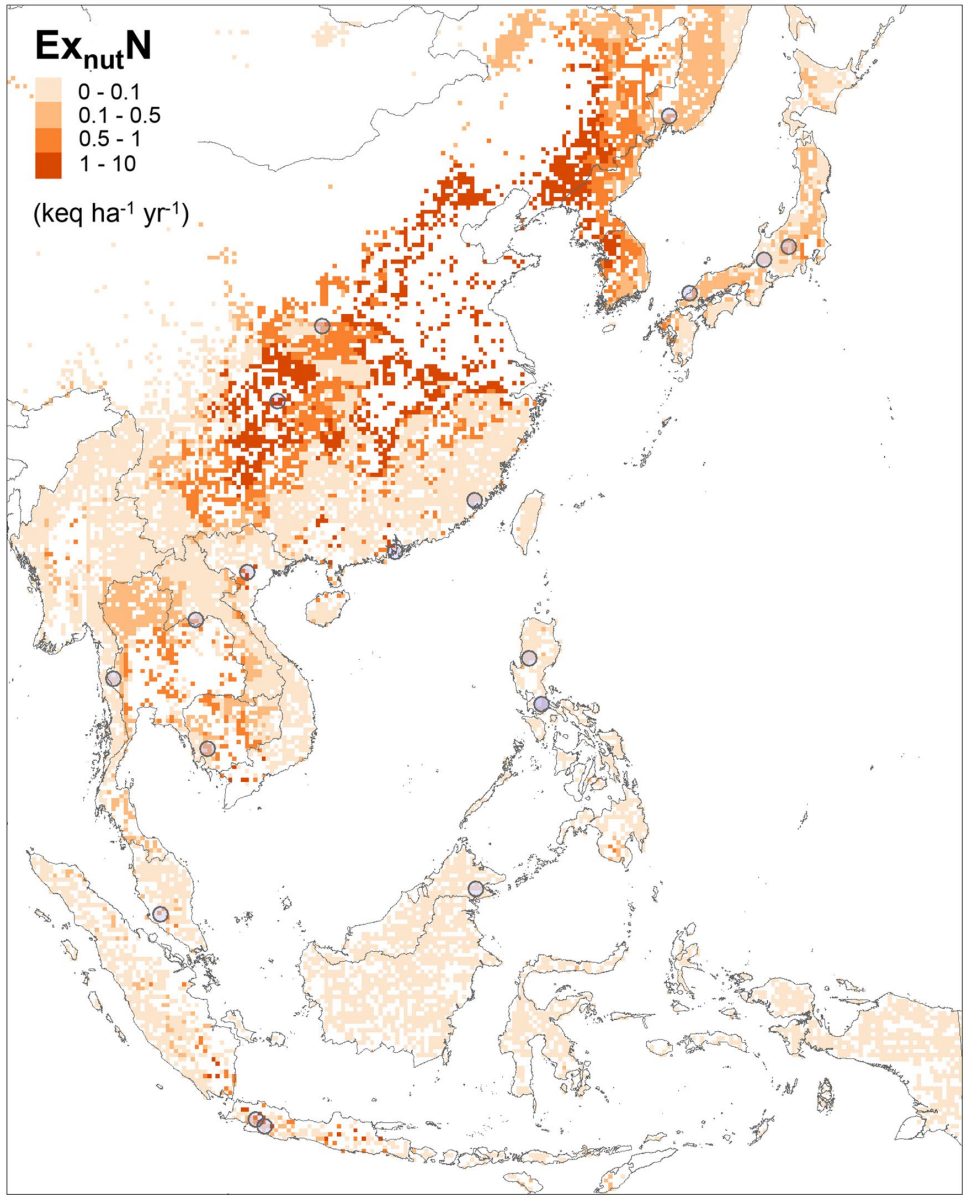


(Yamashita et al., 2022)

Critical load exceedance for soil acidification



Critical load exceedance for surface water eutrophication



(Yamashita et al., 2022)

Critical load exceedance

surface water NO3 trend

Rank	Site_code	$Ex_{nut}N$ (eq ha-1)	NO_3^- (mg L) average	NO_3^- (mg L) s.d.	Spearman's correlation coefficients	p-value	NO_3^- Trend
1	VNI002	1683	1.2	(0.4)	**0.64**	**0.003**	**increase**
2	IDI006	1680	0.1	(0.1)	**0.75**	**0.007**	**increase**
2	IDI004	1680	0.3	(0.3)	**0.47**	**0.049**	**increase**
3	CNI111	1521	2.1	(1.2)	**0.64**	**0.004**	**increase**
4	CNI004	1490	9.6	(2.8)	0.43	0.069	weakly increase
5	CNI007	824	2.3	(1.5)	0.24	0.317	
6	KHI002	696	0.3	(0.2)	-0.14	0.803	
7	THI004	655	0.1	(0.1)	0.11	0.543	
8	LAI001	547	0.2	(0.3)	-0.62	0.269	
9	CNI209	449	3.4	(1.5)	-0.20	0.407	
10	JPI006	431	1.5	(0.5)	**-0.88**	**0.000**	**decrease**
11	RUI004	402	1.7	(1.3)	**0.90**	**0.000**	**increase**
12	PHI003	335	2.6	(6.0)	0.06	0.913	
13	PHI002	68	1.2	(1.9)	-0.19	0.477	
14	MYI001	-179	0.4	(0.3)	-0.30	0.407	
15	MYI003	-271	0.6	(0.3)	-0.25	0.451	

(Yamashita et al., 2022)

Rank of critical load exceedances for eutrophication at EANET monitoring sites and the long-term (max 20years) trends in nitrate concentrations

There was a distinct relationship between areas of the top 4 high N exceedance (high risk) sites and the increasing trend in nitrate there.

Verification → OK!

Critical load exceedance

Soil pH trend

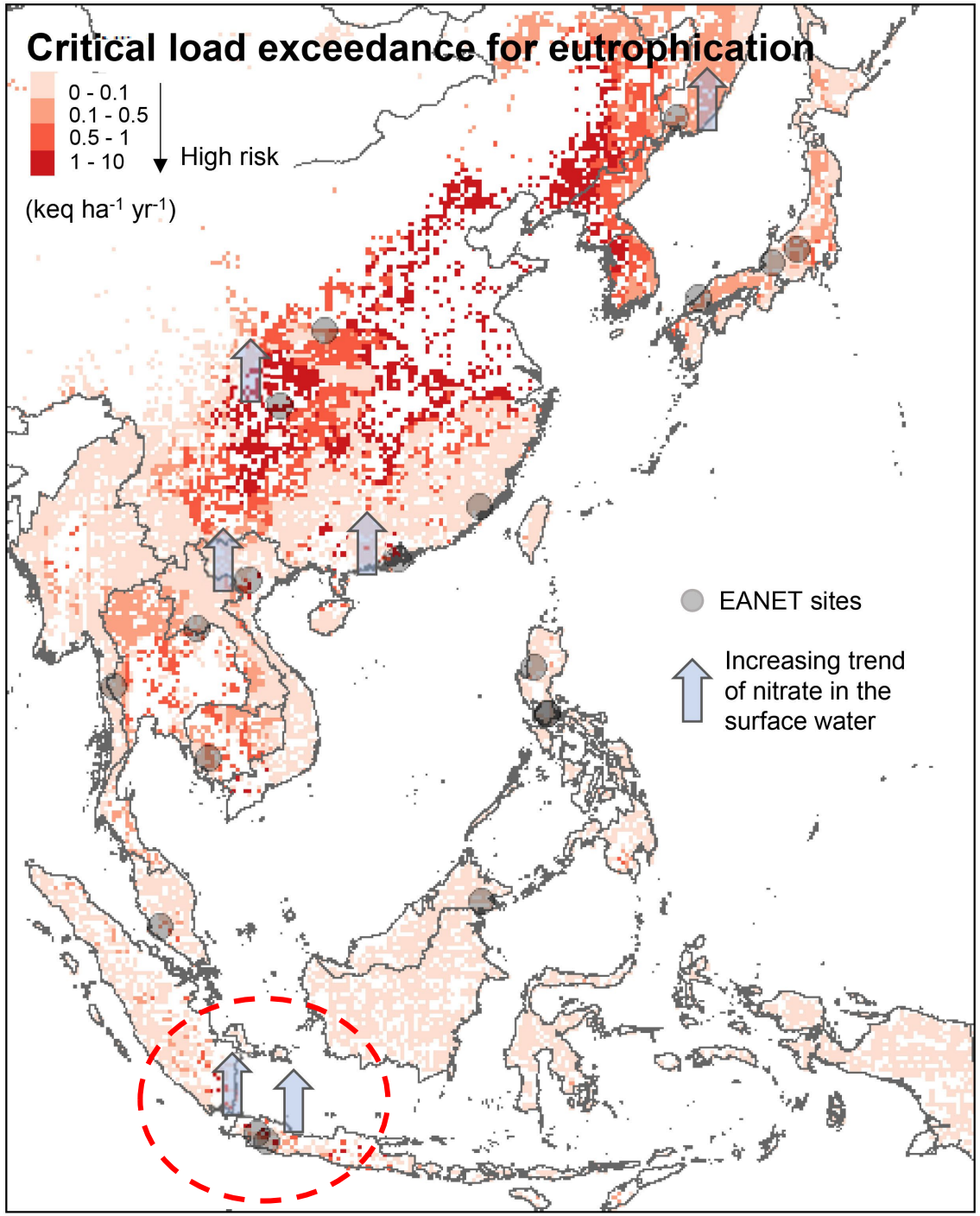
Rank	Site_code	Soil depth	ExS (eq ha-1)	mean soil pH	Linear model coefficient	F-value	p-value	Soil pH trend
1	CNS011	0-10 cm	2288	4.34	0.037	**13.157**	**0.001**	**increase**
		10-20 cm	2288	4.37	0.038	**12.813**	**0.001**	**increase**
2	CNS004	0-10 cm	1871	4.02	0.010	**4.955**	**0.031**	**increase**
		10-20 cm	1871	4.25	-0.010	2.983	0.092	weak decrease
3	CNS009	0-10 cm	1244	4.42	0.022	**4.830**	**0.045**	**increase**
		10-20 cm	1244	4.52	0.019	2.505	0.136	
4	CNS007	0-10 cm	366	6.05	-0.043	**30.775**	**0.000**	**decrease**
		10-20 cm	366	6.18	-0.025	**6.298**	**0.016**	**decrease**
5	THS004	0-10 cm	226	6.38	0.138	**7.770**	**0.021**	**increase**
		10-20 cm	226	6.33	0.020	0.115	0.742	
6	MYS001	0-10 cm	-201	4.22	0.014	**5.137**	**0.045**	**increase**
		10-20 cm	-201	4.53	0.016	**138.957**	**0.000**	**increase**
7	PHS002	0-10 cm	-641	5.07	0.079	**43.678**	**0.000**	**increase**
		10-20 cm	-641	4.90	0.061	**12.289**	**0.002**	**increase**
8	KRS003	0-10 cm	-701	4.94	-0.064	**5.324**	**0.046**	**decrease**
		10-20 cm	-701	4.91	-0.064	5.004	0.052	weak decrease
9	IDS002	0-10 cm	-847	4.23	-0.003	0.480	0.497	
		10-20 cm	-847	4.24	-0.006	0.964	0.339	
10	JPS006	0-10 cm	-1148	4.26	0.013	**12.040**	**0.002**	**increase**
		10-20 cm	-1148	4.38	0.027	**95.970**	**0.000**	**increase**
11	JPS008	0-10 cm	-1536	4.58	0.010	**4.463**	**0.043**	**increase**
		10-20 cm	-1536	4.73	0.012	**12.409**	**0.001**	**increase**
12	MYS005	0-10 cm	-4940	5.15	0.003	0.265	0.619	
		10-20 cm	-4940	5.03	0.009	0.711	0.421	

(Yamashita et al., 2022)

Rank of critical load exceedance for soil acidification at EANET monitoring sites and the long-term trends in soil pH

Soil acidification was not observed at most sites, and there was no relationship with the exceedance.

Verification → Failed..



High-risk areas for surface water eutrophication are estimated not only in Japan, Korea and China but also in the part of Southeast Asia.

Summary

- Critical load maps in East and Southeast Asia were **updated and verified by EANET data.**
- The estimated map of **the critical load exceedance for eutrophication is more plausible** for assessing the risk in East and Southeast Asia than that for soil acidification.
- We found eutrophication (N saturation) risks not only in East Asia but also in **tropical Asia**
- In this stage, the critical load model for soil acidification have a large uncertainty and needs to be revised. We should consider another approach (e.g., a dynamic process model).
- Needs for more research about the **relationship between soil-acidification/eutrophication and plant traits** in this region.
- Needs for **more precise geospatial data** (on going).

Needs for atmospheric modeling ?

- Model development **including tropics**
  - Eutrophication risk might be increasing, particularly around tropical megacities.
- Regional model for **cations deposition**
  - Cations deposition are one of the important input for critical load model
  - Machine learning model (monitoring data-driven) have large uncertainty in this stage.
- Long-term simulation considering **historical emissions** (30-40 years) and future scenarios
  - Critical load model assumes average fluxes for 50 -100 years (*i.e.* steady state assumption).
- Model with **high spatial resolution** considering complex topography in Asian mountain region (< 5-10 km?)
  - The spatial resolution of ecological related information is rapidly becoming a much higher (250 m - 1 km).
  - Especially a elevation might be significant factors controlling rainfall amount (affecting deposition) and ecological sensitivity to the deposition.
  - Mountain area is important source for the watershed-based risk assessment.