Indirect N$_2$O emission of a rice paddy-dominated watershed

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Increasing N\textsubscript{2}O emission

Concentrations of Greenhouse Gases from 0 to 2005

- Carbon Dioxide (CO\textsubscript{2})
- Methane (CH\textsubscript{4})
- Nitrous Oxide (N\textsubscript{2}O)
### Direct V.S. Indirect N$_2$O emission

#### IPCC 2008 Methodology

### Table 6-17: Direct N$_2$O Emissions from Agricultural Soils by Land Use Type and N Input Type (Tg CO$_2$ Eq.)

<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Cropland</td>
<td>103.0</td>
<td>109.8</td>
<td>115.6</td>
<td>117.9</td>
<td>114.7</td>
<td>116.7</td>
<td>118.3</td>
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<td>Mineral Soils</td>
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<td>112.7</td>
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<td>Synthetic Fertilizer</td>
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<td>41.4</td>
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<td>Organic Amendments$^a$</td>
<td>10.0</td>
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<td>11.7</td>
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<tr>
<td>Residue N$^b$</td>
<td>7.0</td>
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<td>7.8</td>
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<td>7.5</td>
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<td>Mineralization and Asymbiotic Fixation</td>
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<td>48.6</td>
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<td>54.7</td>
<td>53.3</td>
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<tr>
<td><strong>Total</strong></td>
<td>156.7</td>
<td>161.8</td>
<td>165.8</td>
<td>170.5</td>
<td>166.0</td>
<td>167.2</td>
<td>170.4</td>
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</tbody>
</table>

### Table 6-18: Indirect N$_2$O Emissions from all Land-Use Types (Tg CO$_2$ Eq.)

<table>
<thead>
<tr>
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<td>Cropland</td>
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<td>33.9</td>
<td>35.7</td>
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<td>35.3</td>
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<td>Volatilization &amp; Atm. Deposition</td>
<td>10.5</td>
<td>11.7</td>
<td>11.9</td>
<td>11.7</td>
<td>12.9</td>
<td>11.3</td>
<td>12.0</td>
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<tr>
<td>Surface Leaching &amp; Run-Off</td>
<td>25.6</td>
<td>22.2</td>
<td>23.8</td>
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<td>22.4</td>
<td>22.7</td>
<td>23.1</td>
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<td>Grassland</td>
<td>10.4</td>
<td>9.7</td>
<td>8.0</td>
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<td>9.2</td>
<td>9.0</td>
<td>9.6</td>
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<td>Volatilization &amp; Atm. Deposition</td>
<td>5.6</td>
<td>5.6</td>
<td>5.1</td>
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<td>5.3</td>
<td>5.2</td>
<td>5.2</td>
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<td>Surface Leaching &amp; Run-Off</td>
<td>4.8</td>
<td>4.1</td>
<td>2.9</td>
<td>4.0</td>
<td>3.9</td>
<td>3.8</td>
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<td>Forest Land</td>
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<td>0.6</td>
<td>0.6</td>
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<tr>
<td>Volatilization &amp; Atm. Deposition</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Surface Leaching &amp; Run-Off</td>
<td>+</td>
<td>+</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
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<tr>
<td>Settlements</td>
<td>0.3</td>
<td>0.5</td>
<td>0.5</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
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<tr>
<td>Volatilization &amp; Atm. Deposition</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
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<tr>
<td>Surface Leaching &amp; Run-Off</td>
<td>0.2</td>
<td>0.3</td>
<td>0.3</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>46.7</td>
<td>44.2</td>
<td>44.3</td>
<td>45.4</td>
<td>45.2</td>
<td>43.8</td>
<td>45.5</td>
</tr>
</tbody>
</table>
Direct V.S. Indirect $\text{N}_2\text{O}$ emission

N input rate
129 kg N hr$^{-1}$

Water area 4%

indirect $\text{N}_2\text{O}$ emission account for 46% of the total $\text{N}_2\text{O}$ emission

Outram, et al. 2012 EST
A significant indirect $\text{N}_2\text{O}$ emission from agriculture

Water area 0.21%

N input rate
$185 + 185 \text{ kg N hr}^{-1}$

Vilain, et al. 2012 Biogeosciences
Production mechanism

Beaulieu et al. 2011 *PNAS*
What is the ratio of indirect N$_2$O emission?

Is it a significant contributor to the agricultural greenhouse gas budget?
Study region

Water area 8.3%

N input rate (paddy rice + wheat)
300 + 250 kg N hr⁻¹

Jurong watershed

Legend
- Reservoir
- Rivers
- Ponds
- Samplings
Experiment design

- 5 ponds sites, 3 river sites, and 1 reservoir site
- Dissolved N$_2$O were collected in 29-mL serum vials previously evacuated according to the method of Terry et al. (1981)
- Two years' continues sampling every 15-20 days
- DO, inorganic N, temperature, pH, and Eh of surface water were also measured
N₂O emission rate calculation

Gas exchange across the water–air interface is calculated by the ‘stagnant – two - film’ (Liss and Slater, 1974, Nature)

\[ F_{N_2O} = V_{tot} \left( C_w - C_a / K_H \right) \]

- \( V_{tot} \): the transfer velocity (m s⁻¹) for N₂O across the water-air interface
- \( C_w \): the N₂O concentration in the surface water of rivers, ponds, and reservoir (mol m⁻³)
- \( C_a \): the N₂O concentration in ambient air (mol m⁻³)
- \( K_H \): the dimensionless Henry’s Law constant (mol m⁻³ mol m_w⁻³)
Climate parameters

Temperature (degree)
- 0
- 10
- 20
- 30
- 40
- 50

Wind speed (m s\(^{-1}\))
- 0
- 2
- 4
- 6
- 8

Rainfall (mm)
- 0
- 100
- 200
- 300
- 400
- 500

Temperature
- Dainly average wind speed
- Monthly rainfall

2010 2011 2012
Indirect $\text{N}_2\text{O}$ emission rate

![Bar chart showing the $\text{N}_2\text{O}$ emission rate from rivers, ponds, and reservoirs over the years 2010 to 2012. The chart indicates that the average emission rate is 7.7 ug N m$^{-2}$ h$^{-1}$.](image)
Compared to the references

-40 -20 0 20 40 60 80 100 120 140
Rivers Ponds Reservoir
ug N$_2$O-N m$^{-2}$ h$^{-1}$

a b
b

Literature
## Total indirect N$_2$O emission

<table>
<thead>
<tr>
<th>Water body</th>
<th>Mean N$_2$O emission rates µg N m$^{-2}$ h$^{-1}$</th>
<th>Water area ha</th>
<th>Indirect N$_2$O flux ton N year$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>River</td>
<td>12.9(± 21.8)</td>
<td>32</td>
<td>0.036</td>
</tr>
<tr>
<td>Pond</td>
<td>4.5(± 16.3)</td>
<td>110</td>
<td>0.043</td>
</tr>
<tr>
<td>Reservoir</td>
<td>7.9(± 10.0)</td>
<td>230</td>
<td>0.16</td>
</tr>
<tr>
<td>In Total</td>
<td></td>
<td>373</td>
<td>0.24</td>
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</tbody>
</table>
Compared to direct $\text{N}_2\text{O}$ emission

<table>
<thead>
<tr>
<th>crop</th>
<th>Total area (ha)</th>
<th>N applications rate (kg N ha$^{-1}$)</th>
<th>Emission factor</th>
<th>Direct $\text{N}_2\text{O}$ emission (ton N year$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>1422</td>
<td>329</td>
<td>0.0042</td>
<td>1.96</td>
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<tr>
<td>Cotton</td>
<td>516</td>
<td>228</td>
<td>0.02</td>
<td>2.35</td>
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<tr>
<td>Maize</td>
<td>229</td>
<td>167</td>
<td>0.02</td>
<td>0.76</td>
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<td>Soybean</td>
<td>200</td>
<td>18</td>
<td>0.02</td>
<td>0.07</td>
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<tr>
<td>Oil rape</td>
<td>973</td>
<td>227</td>
<td>0.02</td>
<td>4.42</td>
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<tr>
<td>Wheat</td>
<td>712</td>
<td>212</td>
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<td>3.02</td>
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<td>Tea</td>
<td>50</td>
<td>41.7</td>
<td>0.02</td>
<td>0.04</td>
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<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>12.63</td>
</tr>
</tbody>
</table>

Yang, et al. 2010 SSPN

\[
\text{Indirect } \text{N}_2\text{O} \quad \text{0.24} \quad \times 100\% \quad \text{1.8%}
\]

\[
\text{total } \text{N}_2\text{O} \quad \text{0.24+12.63}
\]
Compared to N removed by denitrification

<table>
<thead>
<tr>
<th>Water body</th>
<th>Indirect N\textsubscript{2}O \text{(ton N year\textsuperscript{-1})}</th>
<th>N removal \text{(ton N year\textsuperscript{-1})}</th>
<th>N\textsubscript{2}O:N\textsubscript{2} %</th>
</tr>
</thead>
<tbody>
<tr>
<td>River</td>
<td>0.036</td>
<td>4.1</td>
<td>0.88</td>
</tr>
<tr>
<td>Pond</td>
<td>0.043</td>
<td>18.4</td>
<td>0.24</td>
</tr>
<tr>
<td>Reservoir</td>
<td>0.16</td>
<td>24.4</td>
<td>0.65</td>
</tr>
<tr>
<td>In Total</td>
<td>0.24</td>
<td>46.8</td>
<td>0.51</td>
</tr>
</tbody>
</table>

Li, et al. 2013 JSS

membrane inlet mass spectrometry method
Compared to the references

- Rivers
- Ponds
- Reservoir
- Literature

N₂O yield (%)

- a
- b
- c
- d
What are reasons resulting in low $\text{N}_2\text{O}$ emission?

$$\text{N}_2\text{O} = 18.4[\text{NO}_3^{-}-\text{N}] + 0.09 \text{Eh} + 6.1$$
Great runoff is intercepted

Run-off in million m³

Construction and road
14.6

Uplands
5.0

Total river discharge
13.5
Great runoff is intercepted
Great runoff is intercepted

N concentrations through transport
Great runoff is intercepted

As a result, N concentration of outflow is very low
High reducing condition

Low water velocity
High reducing condition

Ponds site: Site1-site 5 ; river sites: site 6-site 8 ; reservoir site: site 9
High reducing condition

Bouman, 1998 Nature

Decreasing N$_2$O/N$_2$ ratio
High reducing condition

$\text{NO}_3^- \rightarrow \text{NO}_2^- \rightarrow \text{N}_2\text{O} \rightarrow \text{N}_2$↑

$y = 0.18x + 19.64$

$R^2 = 0.15 \; P<0.001$
Conclusions

• 1 Though water area is high and N input rate is as high as 600 kg N ha\(^{-1}\) per year in our paddy rice dominated watershed, indirect \(\text{N}_2\text{O}\) emission is disproportionately low.

• 2 This could have resulted from the limited inputs of N into waterways

• 3 Strong reductive conditions as a result of low water velocity might also play a great role.
Question?

- Sampling method?
- Sampling time?
- Sampling site?
Floating chamber method

国家专利号：201120210689.2
Hourly variated emission rate

Measured $\text{N}_2\text{O}$-N flux (ug m$^{-2}$ h$^{-1}$)

Time (h)

Site 1
Site 2
Site 3
Site 4
Site 5
The best sampling time

The first day

The second day
Study region and sample sites

- CR
- IAR
- TAR
- CR
- RES

Nanjing

Jurong
Spatial variation of riverine N$_2$O emission

Average: 27 ug N m$^{-2}$ hr$^{-1}$
Still continuing......
• Xia Y, Li Y, Li X, Guo M, Yan X. Is indirect N2O emission a significant contributor to the agricultural greenhouse gas budget? A case study of a rice-paddy-dominated agricultural watershed in eastern China, Atmospheric Environment, 2013,77:943–950


Thanks a lot!