Groundwater/surface-water interactions and their effect on nitrate pollution in the Oglio River basin (N Italy)

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**Aim of the Work**

**Main aims:**

- assess the origin of nitrates pollution in the area.
- understand how groundwater/surface-water interactions affect nitrate concentrations.

**Methodology:**

- Interpretation of NO$_3$ concentrations (together with major ions and trace elements) and stable isotopes ($\delta^{18}$O/$\delta^2$H in water, $\delta^{18}$O/ $\delta^{15}$N in nitrates and $\delta^{11}$B) measured through 6 field surveys (2015-2017) collecting groundwater, river, lake, spring and rainwater samples.

**Framework:**

- The research project: *Lake, stream and groundwater modeling to manage water quantity and quality in the system of Lake Iseo-Oglio River.*

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Collaborators: [Università di Pavia](#)
Study Area

Oglio drainage basin
6360 km²

Lake Iseo

Oglio River

Elevation (m asl):
- 0
- 150
- 700
- 1400
- 2400
Study Area

Oglio drainage basin
6360 km²

Study area
1960 km²

Lake Iseo

Oglio River

Oglio River

Elevation (m asl):

- 0
- 150
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Geomorphology & Hydrogeology

Alpine Area
Moraine
Higher & Medium Plain
Monolayer Aquifer
Lower Plain
Multilayer Aquifer
River Valley

Springs Belt
Section

Oglio

Conglomerate
Pebble & Gravel
Sand
Silt & Clay
Irrigation

Land Use:

- Agriculture
- Urban
- Industry
- Natural

Irrigation Type:

- Irrigation Channel
- Irrigation Well

Irrigation in the **Higher Plain**:
- **Irrigation channels** fed by Oglio River (diversions all located in its upstream stretch)
- Only in the northern part: **irrigation wells**

Irrigation in the **Lower Plain**:
- On the left bank of the Oglio River: **irrigation wells**
- On the right bank of the Oglio River: **irrigation channels**
Hydrodynamics

Potentiometric Map

Potentiometric map (m asl) for the shallow aquifer in winter 2017

Groundwater flows generally from N to S.

Strong interactions with surface water bodies impart significant variations of its flow direction in the lower plain where the rivers are gaining.
Hydrodynamics

*Groundwater/Oglio River*

Potentiometric map (m asl) for the shallow aquifer in winter 2017

Groundwater flows generally from N to S.

Strong interactions with surface water bodies impart significant variations of its flow direction in the lower plain where the rivers are gaining.
Hydrodynamics

Groundwater head fluctuations

Higher Plain: Surface-water irrigation recharges the aquifer

Lower Plain: groundwater irrigation depletes the aquifer
Hydrochemistry

Data Clustering

On the basis of:

- Results of a preliminary Cluster Analysis
- Results of the hydrodynamic characterization
- Water types

Sampling points were clustered as follows:

- Rainwater (R)
- Lake Iseo (LI)
- Losing stretch of Oglio River (OR lo)
- Gaining stretch of Oglio River in Higher Plain (OR ga-HP)
- Gaining stretch of Oglio River in Lower Plain (OR ga-LP)
- Tributaries of Oglio River (Tr)
- Groundwater in Higher Plain (GW HP)
- Spring (Sp)
- Groundwater in Lower Plain (GW LP)
Nitrate Concentrations

- Rainwater (R)
- Lake Iseo (LI)
- Losing stretch of Oglio River (OR lo)
- Gaining stretch of Oglio River in Higher Plain (OR ga-HP)
- Gaining stretch of Oglio River in Lower Plain (OR ga-LP)
- Tributaries of Oglio River (Tr)
- Groundwater in Higher Plain (GW HP)
- Spring (Sp)
- Groundwater in Lower Plain (GW LP)
The main source of NO$_3$ in the Oglio River is the Higher Plain groundwater.
Origin of Nitrates

*Isotope Sampling*

Survey in September 2016

- $\delta^{15}\text{N}$ & $\delta^{18}\text{O}$ in NO$_3$ measured in:
  - 12 wells from the higher plain
  - 5 Oglio River points
  - 5 springs
  - 1 rainwater collector (March 2017)
Origin of Nitrates

Isotope Sampling

Survey in September 2016

- $\delta^{15}\text{N} \& \delta^{18}\text{O}$ in $\text{NO}_3$ measured in:
  - 12 wells from the higher plain
  - 5 Oglio River points
  - 5 springs
  - 1 rainwater collector (March 2017)

- $\delta^{11}\text{B}$ measured in:
  - 10 wells from the higher plain
  - 4 springs
Origin of Nitrates
\(\delta^{15}N & \delta^{18}O\)

Measured isotopic compositions are in the range of:

- Mixed sources
- Manure, Septic Systems

No denitrification in higher plain groundwater and springs.

Even if rainwater has relevant \(\text{NO}_3\) concentrations, the contribution of rainwater \(\text{NO}_3\) to surface water and groundwater \(\text{NO}_3\) pollution is negligible.

Origin of Nitrates

$\delta^{15}N$ & $\delta^{18}O$

![Graph showing the origin of nitrates with different sources and sampling points.](image-url)
Origin of Nitrates
\[ \delta^{15}N \& \delta^{18}O \]

Mixed sources where large amounts of irrigation water infiltrate the aquifer.

\[ \downarrow \]

Increased dissolution of synthetic fertilizers under intensive irrigation.
Origin of Nitrates

$\delta^{11}B \& \delta^{15}N$

Most of points fall within the range of cow manure and close to the range of sewage.

Three points clearly fall within the range of sewage.

One point clearly falls within the range of cow manure.

No points within the range of uncontaminated water.

Origin of Nitrates

$\delta^{11}B$ & $\delta^{15}N$

Most of points fall within the range of cow manure and close to the range of sewage.

Three points clearly fall within the range of sewage.

One point clearly falls within the range of cow manure.

No points within the range of uncontaminated water.

Nitrates in the Higher Plain are originated from different anthropogenic sources, such as animal manure, septic tanks and, to a lesser extent, synthetic fertilizers.

Factor Controlling NO$_3$ in HP Groundwater
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![Box Plot and Map](map_image.png)
Does surface-water irrigation using Oglio River water (with low NO$_3$) dilute groundwater NO$_3$?
Effect of Irrigation on NO$_3$ in HP Groundwater

**June 2016:**
Beginning of irrigation

**September 2016:**
End of irrigation period

**Effect of Irrigation on NO$_3$ in HP Groundwater**

**June** (beginning of irrigation): increase of NO$_3$ sourced from the leaching (by irrigation water) of the surplus nitrogen from the soils.

**September** (end of irrigation period): this early NO$_3$ spike has been diluted by infiltration of irrigation water, through both fields and unlined irrigation channels.
Final Conceptual Model of NO$_3$ Pollution

- Nitrates are originated from different anthropogenic sources (animal manure, septic tanks and synthetic fertilizers).

- The higher plain represents the main “door” for the entry of these anthropogenic nitrates into the hydrosphere, due to the larger vulnerability of its aquifer (coarser sediments).

- So, nitrates pollution mainly affects the Higher Plain groundwater; however here, surface-water irrigation plays an important and positive role by diluting otherwise-high concentrations of groundwater nitrates.

- Moving downstream, a part of these nitrates enters the Lower Plain aquifer and is naturally remediated by denitrification, whereas another part of these nitrates ends up into the Oglio River, lowering its water quality.
Final Remarks

• To ameliorate the water quality of the Oglio River (in its Lower Plain stretch), restorative actions should be addressed to Higher Plain groundwater.

• The dilution effect generated by surface-water irrigation on NO$_3$ concentrations in Higher Plain groundwater helps to keep groundwater NO$_3$ below the regulatory limit; however this is not the solution of the NO$_3$ problem: dilution or not, the NO$_3$ mass ends up into the Oglio River.

• However, if surface-water irrigation (made with low-NO$_3$ water) will be abandoned in favor of groundwater irrigation, the concentrations of NO$_3$ in Higher Plain groundwater will probably reach higher values, as already happens in the northern part of the Higher Plain.
The effects of irrigation on groundwater quality and quantity in a human-modified hydro-system: The Oglio River basin, Po Plain, northern Italy

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Groundwater and surface water quality characterization through positive matrix factorization combined with GIS approach

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For more details...
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Thanks for your attention!!