Crop Choice and Nitrate Pollution in Groundwater

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Introduction to Nitrates in Groundwater

- Nitrate pollution of groundwater is a top environmental concern affecting people in many regions of the world.
- Ingestion of nitrates in drinking water is linked to several adverse health outcomes, most notably methemoglobinemia in infants, commonly known as blue baby syndrome.
- Domestic wells tend to be most vulnerable to nitrate contamination due to well characteristics and a lack of regulation and regular testing.
- Input-intensive agriculture is a leading source of nitrate emissions into groundwater.
- Dairy farming is of particular concern because of the large quantities of nitrogen-rich manure stored in lagoons and applied to fields. Manure is costly to transport, and field applications are limited to certain crops.
- Evidence of the extent to which land uses cause nitrate contamination of well water – the location where nitrates can cause the most harm – is lacking in the existing literature.
- This paper is among the first to provide evidence of the link between land use and nitrate concentrations measured in groundwater wells and complements existing hydrology literature that typically focuses on predicting nitrate emissions.

Research Question

- To what extent does crop choice and other land uses affect nitrate-nitrogen concentrations measured in California groundwater wells?

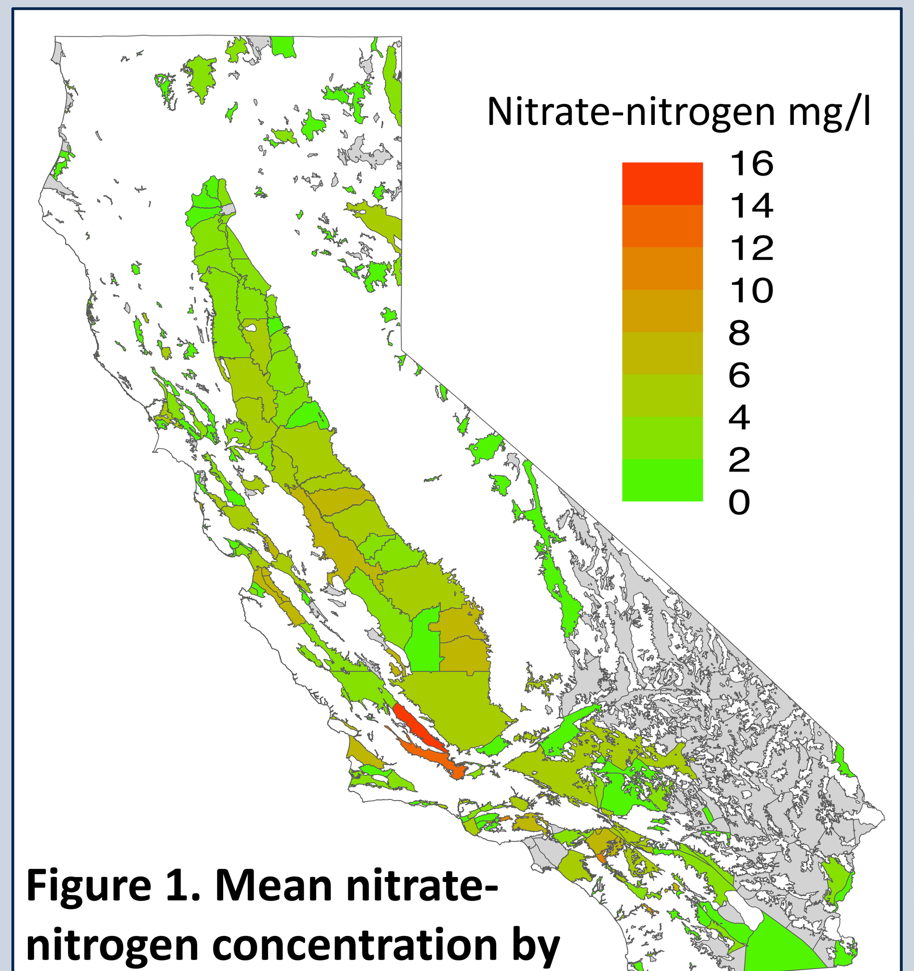

Figure 1. Mean nitrate-nitrogen concentration by subbasin. Mean calculated by pulling well level concentrations from 2007 through 2021. We color subbasins with no well observations in gray and non-basin areas in white.

Data

- We use nitrate-nitrogen concentrations in untreated water sampled from domestic, municipal, and irrigation wells. Nitrate-nitrogen refers to the weight of the nitrogen atom in the nitrate molecule.
- We observe about 6,000 groundwater wells across California.
- Figure 1 highlights the subbasins where we observe wells and the average nitrate concentration across wells and time within each subbasin.
- Annual land use data come from the Cropland Data Layer.
- Figure 2 provides an example of the CDL, where each cell represents 30m^2, and each color represents a crop or other land use.

Analytical Issues

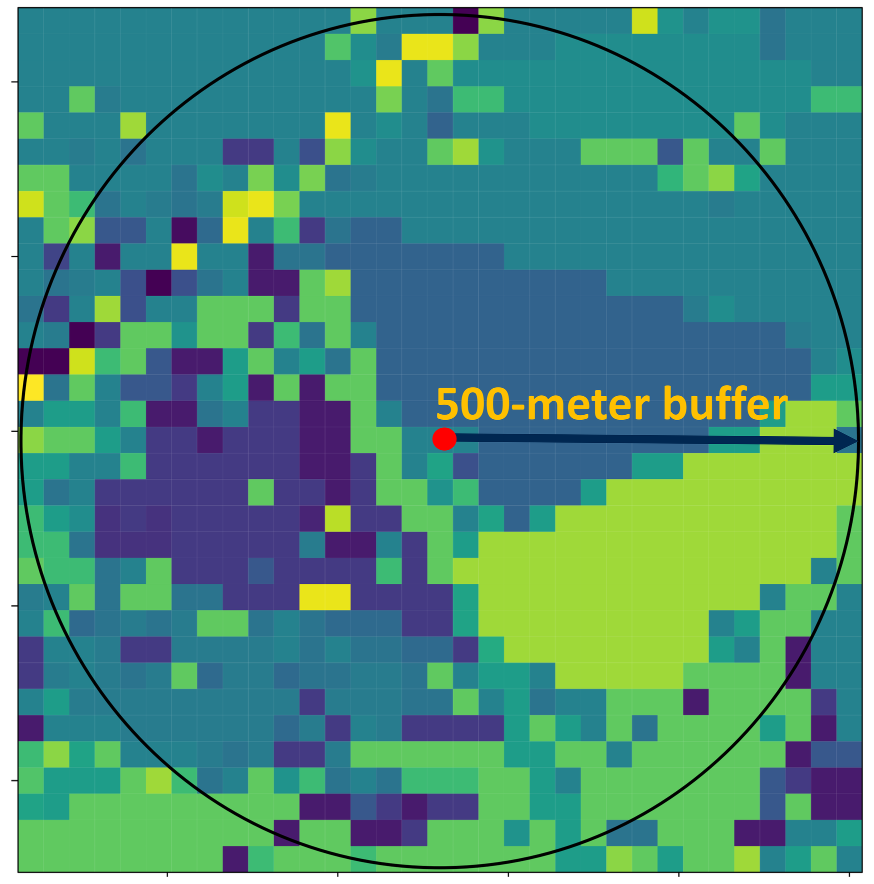

Figure 2. Example of well location, cropland data layer & 500-meter buffer

- We focus on land use and soil characteristics within a 500-meter radius of the well, as illustrated in Figure 2, where the red dot represents the well location, and calculate land use shares within the 500-meter buffer.
- We aggregate crops based on the Nitrate Groundwater Pollution Hazard Index (NHI) (Wu et al. 2005).
- The NHI categorizes crops based on factors such as root depth and the fraction of crop nitrogen harvested.
- Crop NHI examples: Low NHI: rice and alfalfa. High NHI: small grains, corn, tree nuts, tomato, and lettuce.

Data Summary

- **Variation across wells dominates** variation over time for measurements of nitrate concentrations and land use shares.

Table 1. Summary statistics of key variables using data from 2007 through 2021

	Mean	Overall std. dev	Between std. dev.	Within std. dev.
Nitrate-nitrogen (mg/L)	3.2	3.8	4.1	1.25
Low NHI crops (share within 500m)	0.054	0.14	0.12	0.056
High NHI crops	0.097	0.19	0.18	0.061
Pasture	0.12	0.19	0.17	0.07
Developed land	0.54	0.36	0.35	0.047
Undeveloped land	0.16	0.26	0.25	0.058
Fallow	0.026	0.075	0.061	0.044
Thousand dairy cattle within 5km	0.43	1.9	1.9	0

Econometrics

We estimate regression equations of the following form:

$$logN_{ib,T_2} = \boldsymbol{L'_{ib,T_0}\beta} + \boldsymbol{X'_{ib}\gamma} + \alpha \log N_{ib,T_0} + \lambda_b + \varepsilon_{ib,T_2}$$

where $logN_{ib,T_2} = \frac{1}{5}\sum_{t=2017}^{2021} logN_{ibt}$, $logN_{ib,T_0} = \frac{1}{5}\sum_{t=2007}^{2011} logN_{ibt}$, and $L_{ib,T_0} = \frac{1}{5}\sum_{t=2007}^{2011} L_{ibt}$. Subscript i denotes wells and b denotes subbasin. Vector $\boldsymbol{\beta}$ captures the effect of land use shares, $\boldsymbol{\gamma}$ captures effects of controls like soil and well characteristics, and λ_b captures subbasin fixed effects.

Results and Discussion

Table 2. Results of mean log nitrate concentrations in recent years (2017-2021) regressed on mean land use shares in the past (2007-2011) and other controls

	(1)	(2)
Low NHI crops	.049	.023
High NHI crops	.38**	.34**
Pasture	.18*	.17*
Developed land	.17**	.17**
Fallow	.11	.085
Thousand dairy cattle within 5km of well		.019***
Total surface water deliveries, 2007-2021 (Ac Ft)	.000081	.000082
Total precipitation, 2007-2021 (meters)	-.028	-.026
Depth to groundwater (meters)	.00038	.00039
Depth to well screen top (meters)	.00014	.00014
Well screen length (meters)	-.00081***	-.00082***
Share of land with subsurface tile drainage	-.35*	-.36*
Sand (share of soil texture)	-.19	-.21
Silt (share of soil texture)	-.46	-.49
Organic matter (share of total soil weight)	.67	.68
Porosity	.011	.011*
Distance to river (kilometers)	.0059	.0048
Mean log(Nitrate concentration) in 2007-2011	.84***	.84***
Subbasin fixed effects	Yes	Yes
R^2	0.76	.76

Note: Undeveloped land is the reference land use and clay is the reference soil texture fraction. Both regressions include 5,510 observations. We cluster standard errors by subbasin (228 clusters) and exclude the standard errors here for brevity. * p<0.10, ** p<0.05, *** p<0.01

- High NHI crops, pasture, and developed land increase groundwater nitrate concentrations relative to undeveloped land. For example, from column 2, a one percentage point increase in the average share of land used for high NHI crops (say from 10% to 11%) is associated with a 0.34% increase in nitrate concentrations within approximately 10 years relative to undeveloped land.
- Controlling for the local dairy cattle population decreases the magnitude of the coefficients on the agricultural land use shares, suggesting manure management plays a role in emissions from local cropland.
- A permanent 1,000-cow increase in the dairy cattle inventory within 5 kilometers of a groundwater well leads to a 1.9% increase in nitrate concentrations measured at the well within approximately 10 years.

Reference

Wu, L., J. Letey, C. French, Y. Wood, & D. Birkle. 2005. "Nitrate leaching hazard index developed for irrigated agriculture." *Journal of soil and water conservation* 60(4), 90A–95A