Review of: hess-2024-173

Title: Assessing the long-term effectiveness of nitrogen management for groundwater protection in the agricultural crop production sector in Wallonia, Belgium
Author(s): Elise Verstraeten et al.

Introduction

This paper provides a statistical analysis of nitrate concentration time series (2002-2020) in 36 groundwater sites for drinking water production in the Walloon region of Belgium for the purpose of evaluation of the effectiveness of Sustainable Nitrate Management Program (PGDA). For this they constructed a dataset of variables that are expected to explain six indicators for levels and trends observed nitrate concentrations. The main conclusion as in the Abstract are:

1. a modest overall improvement in average nitrate concentrations,
2. an encouraging a slowdown in the rate of increase,
3. land use patterns and aquifer characteristics to be key determinants,
4. a time lag between the introduction of regulatory measures and the observable impact.

Review summary

Having a quite long experience on studying and publishing about nitrate risks in drinking water and evaluation of fertilizer and manure policies as an implementation of the EU Nitrates Directive, I was keen to review this paper. In depth explanatory studies of the response of nitrate in deeper groundwater for drinking water are quite rare, while protection of drinking water resources is a major goal of EU Nitrates Directive,

The paper is well organized and in mostly well written. However, after reading I found the conclusions a bit obvious and general. I also missed several relevant and available explanatory data, for example the nitrogen surplus (or Gross Nitrogen Balance) and proof of insight in the nitrogen cycle. While aiming to support and contribute to the Walloon nitrate policies, the paper is not providing any detail on the policy measures and how these could relate to observed nitrate trends. Finally, I also found that the introduction of nitrate issue missed recent insights.

The statistical analysis, using the six indicators and the two approaches to detect inflection points is sound and quite original, but unfortunately fails to deliver policy relevant conclusions. Results and discussion hardly transcend to the level of describing the results of the statistical analysis and miss a translation to relevant, new conclusions about the effectiveness of the Walloon implementation of the Nitrates Directive or about the mechanism of response of nitrate in aquifers to inputs and other factors.

So, to my regret I have to conclude that this paper does not deliver many new insights. I also doubt whether Walloon policy makers find it very informative or useful to modify their next action plan for EU Nitrates directive (which the authors write they want to do). As I was not very familiar with the N fertilizer policies and nitrate pollution in Wallonia, I also looked for some publications and data.

From this I get the impression this works is not well connected to ongoing work and evaluations of the Walloon implementation of the Nitrates directive (which is mandatory every 4 years)[1].

I also would expect that reconstructing or projecting spatially explicit trends of nitrate concentrations in aquifers would typically require process oriented numerical simulation models (like for example MODLFOW). While the authors make some reference to this type of modelling in the discussion, they not clearly explain why they choose for the data driven regression models in this study. While I don't want to downplay the investment in using numerical groundwater simulation models (preferably you would team up with experts which already operationalized the model), the chosen statistical approach also appears to have been quite time consuming while (in my opinion) not providing clear answers about effectiveness of policy are legacy effects.

In case the editor would decide for a revise – resubmit of this work the revision should in my view focus on:

1. Adding more information and insight on the N cycle and N budget of the Walloon region and the consequence for the N loading of Walloon aquifers
2. Connect and refer to the publication of "Bilan d'azote en agriculture et flux d'azote des sols vers les eaux"(21 décembre 2022 by État de l'environnement Wallon and show the added value your work. This includes showing the added value of your statistical regression approach versus a simulation approach (http://etat.environnement.wallonie.be/contents/indicatorsheets/SOLS%204.html).
3. Derive and formulate more relevant conclusion for Walloon policy makers regarding the implementation of the EU Nitrates directive.

Review remarks in more detail

Abstract

I found it quite long.

L8: Optimizing towards which target? I suspect farm income.

L20-29: I found your findings not very specific or new, e.g., for the Walloon policy makers or farming community. What is your message for them?

Introduction

L31-33. The "Blue baby" story is obsolete (the number of cases in Europe is close to zero). While the excellent review of Mary Ward still stands, the consensus is that colorectal cancers pose the largest risk (see e.g., Schullehner, J., Hansen, B., Thygesen, M., Pedersen, C. B., & Sigsgaard, T. (2018).

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[1] 1Interestingly Wallonia was involved in the international network for Monitoring effectiveness of the EU Nitrates Directive Action Programs (so-called MonNO3 workshop). The first one was in 2003. See e.g., Delloye, et al. (2005): Approach by the Walloon Region. (in Fraters et al..2005: Monitoring effectiveness of the EU Nitrates Directive Action Programmes. Rijksinstituut voor Volksgezondheid en Milieu, the Netherlands, 85-105). The Delloye, et al. paper on the Walloon situation in 2003 could have been nice reference point for this paper (fyi; there was a 2nd MonNO3 workshop in 2009, which later merged Land use and water quality conference. Water LUWQ).

Nitrate in drinking water and colorectal cancer risk: A nationwide population-based cohort study. International journal of cancer, 143(1), 73-79.).

L35: Environmental “threat”?

L41: which regions where: Europe, Belgium?

L44: the 50 mg/l criterion in the Nitrates Directive applies to all waters.

L49: quite old references; these authors have published more recently about the nitrate issue.

L50-54: The list of standard measures for NVZs sometime aim at protection of surface water (e.g., closed period for fertilizer and manure application on steep slopes, frozen ground) some more for groundwater (cover crops, balanced fertilization). I would suggest providing more detail and use these for your statistical analysis. I also wonder if in Wallonia additional measures (beyond requirements for Nitrates Directive) for regions where groundwater (or surface water) is used for drinking water production (in my country, The Netherlands, we have groundwater protection zones – “ grondwater-beschermings-gebieden” with more restrictions than in NVZs).

L63-66: Suggest formulating this as a (or a few) clear research hypothesis. Suggest also to delete “landscape elements” and not only refer to accumulation but also to retardation of nitrate by chemical transformation to N2 and N2O (denitrification).

L68-72: In my experience from the Netherlands Action Programs (or Plans) for implementation of the Nitrates Directive need to be evaluated and renewed every 4 years. Is this not the case for Wallonia, and if so, there must a history of evaluation report available. Please check and add.

L111-117 You explain that you exclude points with anoxic groundwater using a certain criterion. By this you focus on sites with higher risks of nitrate leaching to deeper aquifers. Why this is valid I would think that denitrification potential still can be an important explanatory variable? For example, for the upper soils it is the depth of the groundwater table and presence of organic material (to deliver the nitrate reduction) and deeper also the presence of pyrite in geological formations is an important factor for the denitrification potential. Can you explain, or justify why denitrification potential is not included or considered?

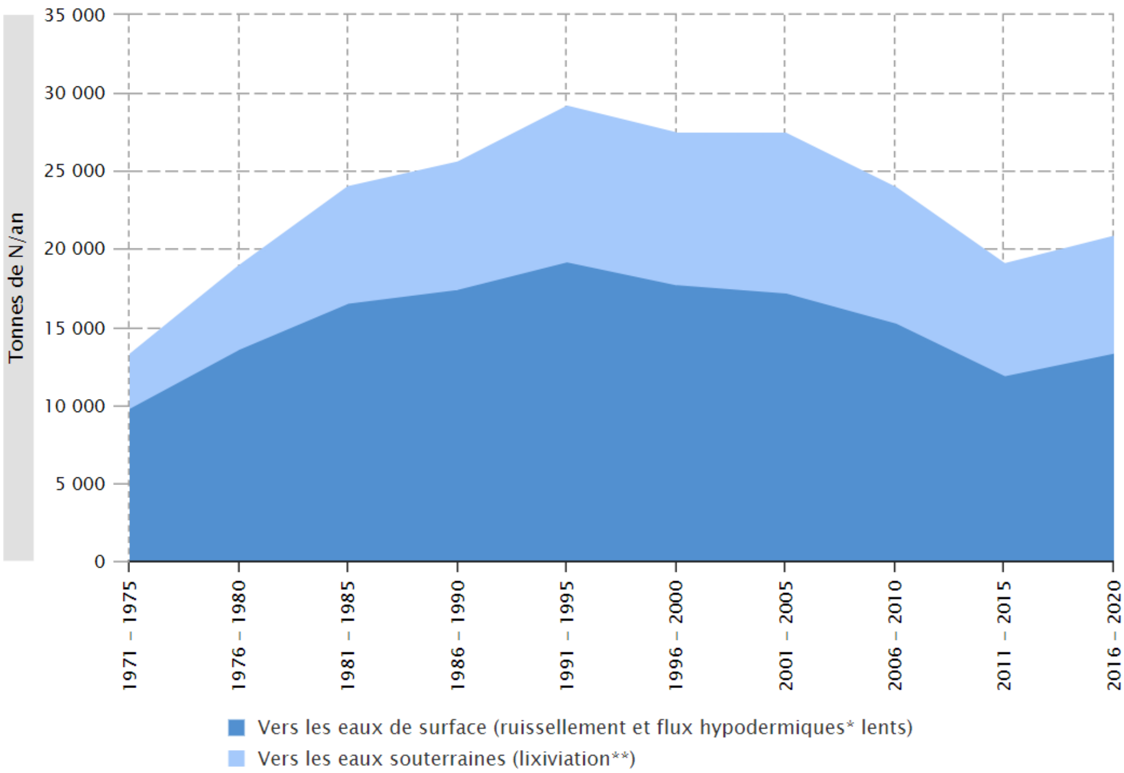
L184-186. What do you mean by the “we used the depth of (the bottom part of) the water intake structures as a proxy of the depth to the groundwater table”? In the Netherlands, the depth of groundwater intake for drinking water production (50-100 m) is much deeper than the phreatic groundwater table (1-2 m)

L186: Why not use rainfall and not precipitation surplus? I assume that this information is available (like in the Netherlands and also in maps).

L197-2001. Why use land cover and land use as proxies for nitrogen load while there is trend information on N input and N surplus available, regarding input, also per crop for Wallonia, and also mapped. See e.g.

http://etat.environnement.wallonie.be/contents/indicatorsheets/SOLS%204.html

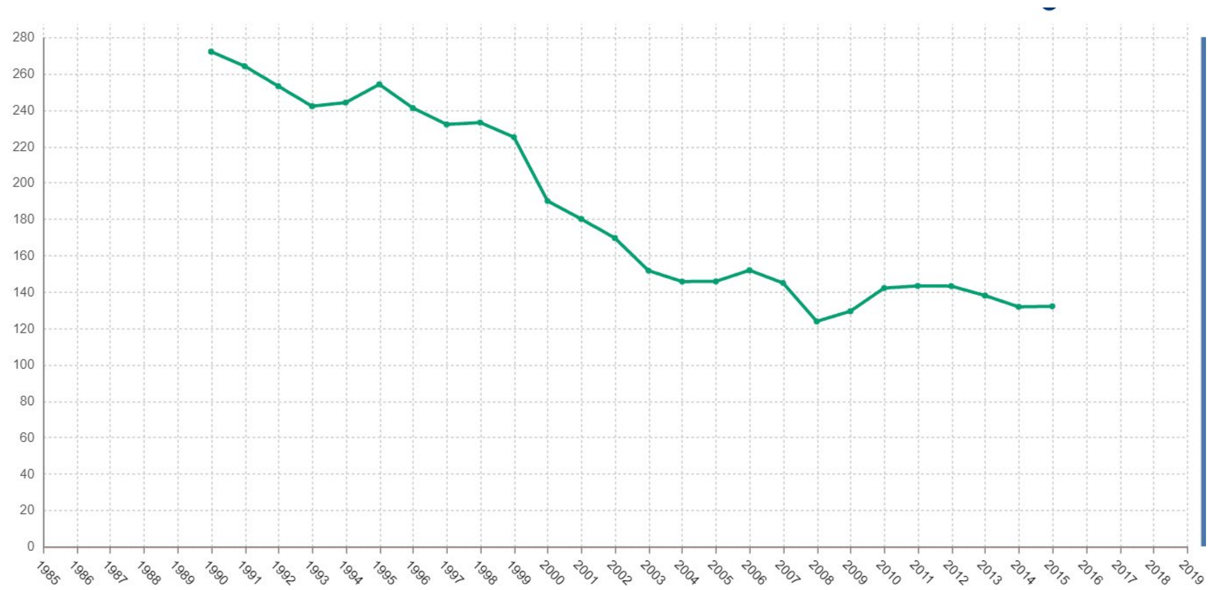
The evolution of the (modelled) N load to groundwater in the figure below looks quite similar to that of the observed nitrate concentration in your Figure 4, but with an apparent delay of 10-20 years. This indicates that a more process-oriented approach is better and possible.



Also, Eurostat provides time trends for N input and surplus, but only for Belgium as a whole.

https://ec.europa.eu/eurostat/databrowser/view/aei_pr_gnb__custom_12226009/default/table?lang=en

See below the evolution of the Gross Nitrogen Balance (kg N/ha).

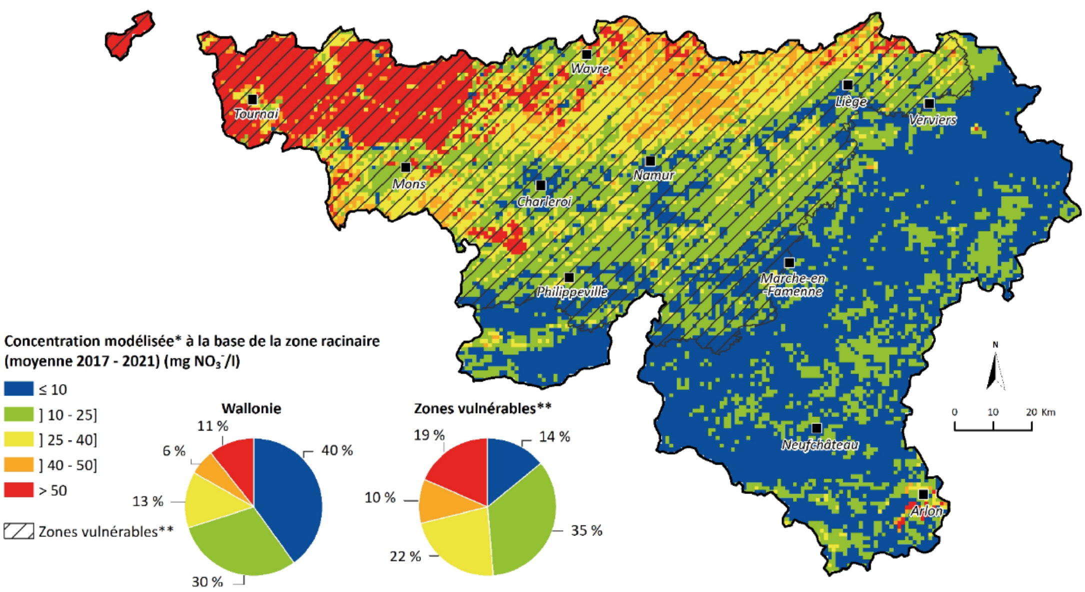


This type of data is available and provides direct insight in the evolution of nitrogen loads on the aquifer. I found it very surprising that this type of data is not used for this paper, as it obviously is an important explaining variable. I am pretty sure there is also data on N loads form other sources than agriculture which could help to provide insight into the relative importance of different sources of nitrates and distinction of diffuse (non-point) and point sources (see e.g. the European Nitrogen

Assessment4, 2011, Chapter 16; Leip, A., Achermann, B., Billen, G., Bleeker, A., Bouwman, A., de Vries, W., ... & Winiwarter, W. (2011). Integrating nitrogen fluxes at the European scale). I miss an overview of the relative strengths of all nitrogen sources as well as their potential contribution to polluting groundwater resources for drinking water production.

Table 2 Elaborating on the previous point, I found it surprising that the authors did not include any variable in Table 2 related to N loading of the aquifer and specific measures as in the PGDA, and how these change over time. The included variables related to land use, and, in case of meadow, the area trends are, in my view, very coarse proxies, especially for these N loads. I can understand that your choice for land use as an explanatory variable allows a spatially explicit approach, however the website of the "État de l'environnement Wallon" also shows a map of modelled nitrate (http://etat.environnement.wallonie.be/contents/indicatorsheets/SOLS%204.html). This official publication by the Walloon government appears more advanced than yours.

Concentration en nitrate (NO_3^-) dans les eaux de percolation en Wallonie (2017 - 2021)



* Modèle EPICgrid[(a)] (SPW ARNE - DEE) - Maille de 1 km²
** Zones dont les sols sont susceptibles d'alimenter en azote des masses d'eau déjà impactées (dépassement ou risque de dépassement du seuil de 50 mg/l en eaux de surface ou souterraines, eutrophisation ou risque d'eutrophisation en eaux de surface). Des mesures particulières (contrôle de l'azote potentiellement lessivable p. ex.) s'y appliquent dans le cadre du PGDA .
REEW – Source : SPW ARNE - DEE (modèle EPICgrid)

I also suspect that several of the "potential explanatory variables" are correlated, e.g., land use by meadow, crops and forest and green (nature?) must add up. Before you start the correlation and regression analysis for observed nitrate it is wise to check for these autocorrelations. This information perhaps also can be used to reduce the number of variables.

L203-206. I assume by "punctual" you "mean" point sources? But more importantly, I miss a clear motivation. Common sense is that in northwest Europe or the EU in general, non-point pollution from agriculture is the dominant source of soil and groundwater pollution. When focusing on specific regions for drinking water production this can be different as the groundwater abstraction areas are smaller and often protected areas. For example, I would be surprised when (active) graveyards or large sceptics tanks are located (or allowed) in drinking water abstraction areas. Please explain.

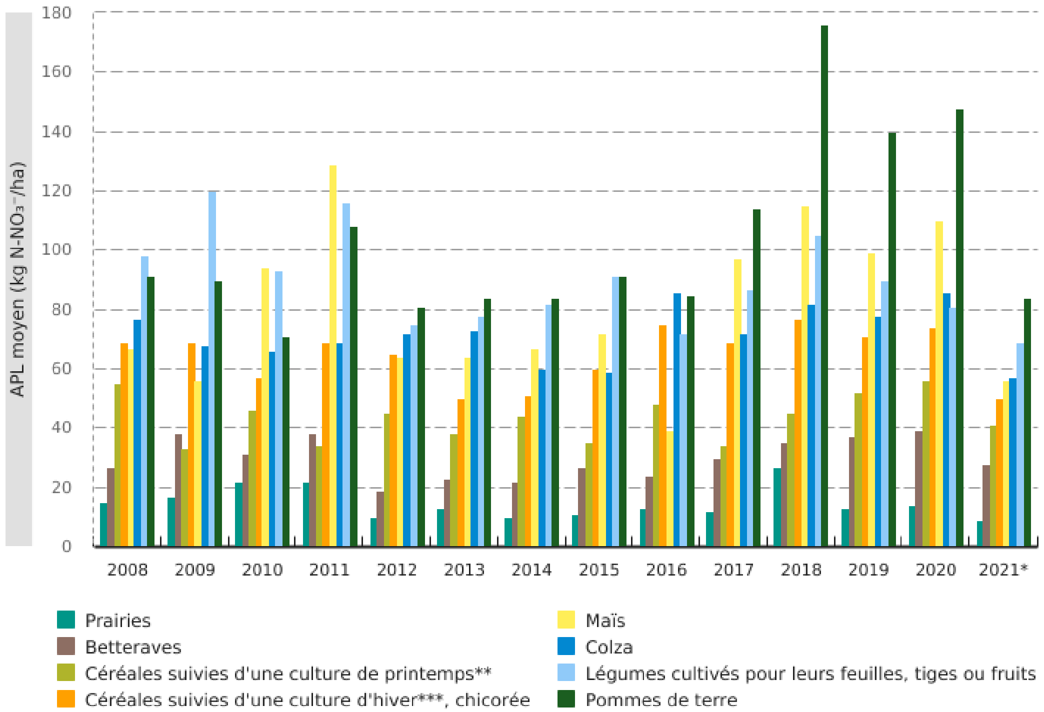
Table 4: Why do you average descriptive statistics for all 4 sites, while their characteristics are quite different? The histograms in Figure 5, are quite original but also a bit unusual and the "count" is lumped way of presenting the difference in nitrate levels and trends between the four groundwater bodies.

L313-217: Why "trend likely due to higher conductivity and renewal rate"? Don't trend and legacy effects also depend on other factors, like denitrification, the volume of the aquifer. Intuitively you may expect that sandy aquifers respond more quicky to changes in total N load than chalk aquifers, but if the volumes are very different, I would not be so sure. Figure 5 to some extent confirms that monitoring sites in the sandy groundwater bodies show more decreasing nitrate trends.

L325. Indeed, potato is known for having high N surpluses, while grassland is known to have low N surpluses. But the nitrate effect also strongly depends on the denitrification potential of the soil and aquifer. There is quite a history of literature on this in the Netherlands and I guess also the Flemish region (see e.g. Dico Fraters, Ton van Leeuwen, Leo Boumans & Joan Reijs (2015) Use of long-term monitoring data to derive a relationship between nitrogen surplus and nitrate leaching for grassland and arable land on well-drained sandy soils in the Netherlands, Acta Agriculturae Scandinavica, Section B — Soil & Plant Science, 65:sup2, 144-154, DOI: 10.1080/09064710.2014.956789). Also keep in mind that potato is always cultivated as part of a rotation of crops (e.g., a grain and sugar beet).

Furthermore, in the previously given website for the Walloon nitrogen data (http://etat.environnement.wallonie.be/contents/indicatorsheets/SOLS%204.html) you can find data for this (see below), which show both that potato is a crop with higher nitrate risks but differences with other major crops (cereals, sugar beet, maize) change over time. Why did you not use this type of information or team up with people collecting and interpreting this data?

Azote potentiellement lessivable (APL) contrôlé en zones vulnérables en Wallonie. Valeurs moyennes par classes de culture



* Données provisoires

** Le sol est laissé nu ou couvert d'une culture intermédiaire piège à nitrate (CIPAN) entre la culture de céréales et la culture implantée au printemps de l'année suivante.

*** Culture implantée en automne (froment d'hiver, orge d'hiver, colza d'hiver...), après la culture de céréales

REEW – Sources : PROTECT'eau ; GRENeRA

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At this point I stopped reviewing in detail your discussion as in my opinion it is a too basic discussion of statistical results while lacking a more process-oriented analysis of transport and (chemical or micro-biological) transformation of nitrogen loads that vary in time and space. I have doubts if this paper uses the recent insights in Belgium about this issue. I also wonder if there are studies using process-oriented model to reconstruct or project trends of nitrate in aquifers.