Qualitative Evaluation of Climate Change Effects on Nitrate Occurrence at Several Aquifers in the Catalonia Inner Basin

J. Mas-Pla, A. Menció and L. Portell

1 Introduction

Groundwater nitrate pollution is a ubiquitous worldwide problem that has been in the managers, as well in the researchers, agenda for decades. Multiple efforts have been devoted to improve agricultural practices, so nitrogen leaching due to fertilization is minimized, as well as to track its movement through the unsaturated zone and within the aquifer. Biogeochemical processes have also been researched to identify in situ denitrification processes which can be subsequently used to induce nitrate removal from groundwater. Despite all these efforts and knowledge, present nitrate concentrations in groundwater reflect the impact of decades of nitrogen inputs. Dilution stands as one of the major natural processes that diminish nitrate concentration in aquifers. Mixing between polluted water resources and less-polluted inputs reduces this environmental pressure. Dilution, at the end, relies on the input of non-polluted water fluxes.

In many regions on Earth, climate change will represent a shift towards drier conditions (IPCC 2014). Consequently a modification of their water balance and a diminution of the aquifer dilution capacity will occur. Therefore, an increase of nitrate concentration can be predicted. The goal of this contribution is to explore the effects of climate change upon the occurrence of nitrate in groundwater at a regional scale and in the long run. To conduct such objective, an approach founded on the basin water balance analyzes is used. In this sense, we consider the variation that each component of the hydrological cycle will experience under new climatic

---

J. Mas-Pla (✉) · L. Portell
Institut Català de Recerca de l'Aigua (ICRA), c/ Emili Grahit, 101, 17003 Girona, Spain
e-mail: jmas@icra.cat

A. Menció
Grup de Geologia Aplicada i Ambiental (GAiA-Geocamb), Deptartament de Ciències Ambientals, Campus de Montilivi, Universitat de Girona, 17003 Girona, Spain

M. L. Calvache et al. (eds.), *Groundwater and Global Change in the Western Mediterranean Area*, Environmental Earth Sciences,
https://doi.org/10.1007/978-3-319-69356-9_25

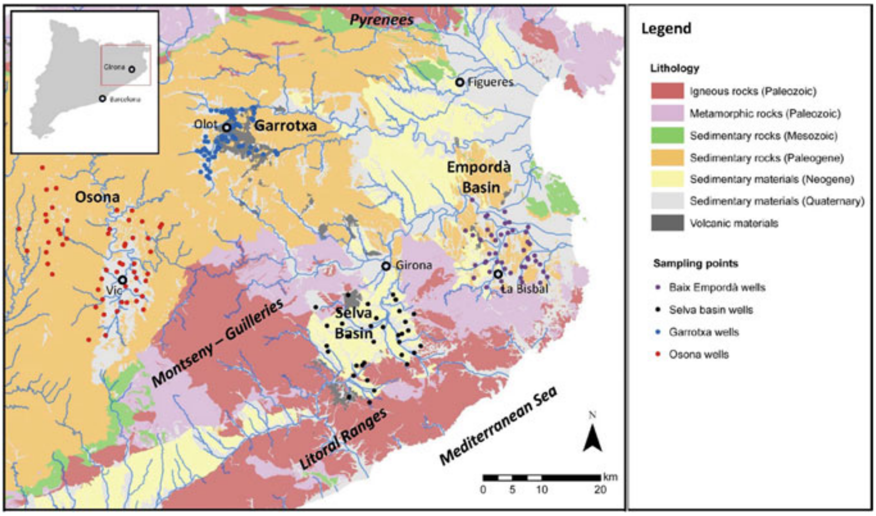

Fig. 1 Geographical locations and geological setting of the studied areas

scenarios and similar water uses, and how these changes will affect groundwater nitrate content.

During the last fifteen years, the extent of nitrate pollution and the occurrence of denitrification processes from a hydrogeological and hydrogeochemical perspectives has been studied by several projects in distinct aquifers of Catalonia, all of them declared as vulnerable to nitrate pollution as a result of EU directives (Fig. 1).

Our approach refers to the paradigmatic study on the impact of climate change on future nitrate concentrations in groundwater of the UK by Stuart et al. (2011). They focus on the idea that climatic changes would likely affect groundwater recharge mechanisms and, the way they will affect groundwater receptors.

2 Methodology

This study consists on the interpretation of already existing data from nitrate polluted aquifers under the future climatic scenarios (i.e., horizons 2021 and 2050), and the subsequent modifications of the water budget for each hydrogeological system. Data from each aquifer have been reported in the following references: according to published results in the Selva basin (Folch et al. 2011; Puig et al. 2013), Empordà basin (Puig et al. 2017), Osona region (Otero et al. 2009; Menció et al. 2011; Boy-Roura et al. 2013b), and Garrotxa (Bach 2015; unpub. data). Details in land use and pollution levels in these aquifers are summarized by Menció et al. (2016).

Climatic conditions for the above-mentioned horizons were calculated after a downscaling process from global circulation models by Calbó et al. (2016). This reference provides the averaged temperature increment and rainfall variations for different geographical/climatic areas in Catalonia. Water budgets for 2021 and 2050 in the hydrographic basins of Catalonia, with special interest of those corresponding to the studied aquifers, were estimated by Mas-Pla et al. (2016) using the climatic projections by Calbó et al. (2016) and the percentage of land-use as determined by Zhang et al. (2001) approach. To differentiate between run-off and infiltration terms, we use a map of average recharge based on the chloride mass balance by Alcalá and Custodio (2014).

We herein profit from these references and use their results to discuss the impact of climate change on nitrate pollution for distinct hydrogeological settings using a water balance approach (e.g., Fitts 2012, pp. 13–16; Menció et al. 2010).

3 Results

3.1 Hydrology and Water Quality in the Selected Aquifers

Data from the studied regions are summarized for each aquifer (Table 1); in particular: (1) aquifer type (water-table, leaky, or confined), (2) origin of recharge: direct rainfall (representing soil infiltration and, therefore, leaching of soil nutrients and applied fertilizers), interaction with streams (considering discharge regime), and occurrence of recharge from mountain fronts or the basement according to the geological setting; and (3) mean and median nitrate content, percentage of samples with $[NO_3] > 50$ mg/L, and (4) mean, median of $\delta^{15}N_{NO_3}$ values, and percentage of denitrification based on the multi-isotopic approach. They provide a brief indication of their present state and of potential alternatives under future climatic scenarios.

3.2 Hydrology and Water Quality in the Selected Aquifers

Present climate projections derived from climatic/atmospheric models provide estimates for temperature (T) and precipitation (P) variations for the next decades. In most cases, downscaling processes are necessary to refine such predictions, and to offer more appropriate data to hydrologists so future water budgets can be estimated with the predicted parameters. Calbó et al. (2016) calculated the seasonal and annual temperature and precipitation projection for 2021 and 2050 using distinct climatic databases, as well as different downscaling methods, for each geographical area in Catalonia: Pyrenees, inland areas and coastal areas. Major results are given in Table 2. Scaling is necessary, especially as regards rainfall, as in areas such as Catalonia, the complex orography and land-sea contrast are largely misrepresented by global models.

Table 1 Summary of the main hydrogeological and chemical status of the aquifers considered in this study. Data after references cited in the text

	La selva	Osona	Empordà	Garrotxa
Aquifer lithology: Bedrock, sedimentary infilling, alluvial	S-A	B-A	S-A	B-A
Recharge origin: local, regional	L-R	L-R	L-R	L
Aquifer type: unconfined/multilayered/leaky	U-M	M	U-M	U-M
$[NO_3]$ (mg/L): mean/median/% > 50 mg/L	65/59/51%	165/92/72%	100/67/57%	35/29/22%
$\delta^{15}N_{NO_3}$(‰): mean/median/% > 15‰[a]	10.8/10.4/7%	14.0/13.4/28%	12.9/12.2/22%	9.9/9.4/6%
Land-use: forested/agricultural	A	A	A	F - A
Groundwater exploitation: seasonal, non-seasonal	NS (livestock) S (agriculture)	NS (livestock) S (agriculture)	NS (urban)—S (agriculture)	S (agriculture)
Alternative resources:	Water reclamation	Ter river (mid-basin)—water reclam.	Ter river (lower-basin)—water reclamation	Fluvià river
Other pressures, hazards:	Local as, F high levels	(none)	Seawater intrusion—over-exploitation	(none)

[a] Values of $\delta^{15}N_{NO_3} > 15$‰ are assumed to be indicative of denitrification processes

Table 2 Annual median temperature and rainfall variations for the 2021 and 2050 horizons in Catalonia with respect to 1971–2000. Data in parenthesis correspond to the 5th and 95th percentile. Data after Calbó et al. (2016)

	Climatic area	Pyrenees	Inland areas	Coastal areas	Catalonia
2021	ΔT (°C)	0.8 (0.5/1.1)	0.7 (0.5/1.0)	0.7 (0.5/1.0)	0.8 (0.5/1.0)
	Rainfall (%)	−0.2 (−7.8/8.0)	0.7 (−14.1/8.0)	−2.4 (−20.7/6.0)	−2.4 (−13.4/5.8)
2050	ΔT (°C)	1.6 (0.9/2.2)	1.4 (0.9/2.1)	1.4 (0.9/2.0)	1.4 (0.9/2.0)
	Rainfall (%)	−5.3 (−16.1/−1.2)	−6.5 (−23.7/1.4)	−8.5 (−27.1/2.3)	−6.8 (−22.0/−0.7)

Table 3 Summary of available resources, as R/P, according to published data

		LA SELVA	OSONA	EMPORDÀ	GARROTXA
R/P—2015[a]		0.292	0.287	0.238	0.380
R/P—2021[a]		0.278	0.265	0.229	0.357
R/P—2050[a]		0.254	0.258	0.206	0.338
Average groundwater recharge, R(gw)/P[b]		0.120	0.200	0.150	0.220
2021	R(sw)/P	0.158	0.065	0.079	0.137
2050	R(sw)/P	0.134	0.058	0.056	0.118

sw surface water
gw groundwater
[a] Mas-Pla et al. (2016)
[b] Alcalá and Custodio (2014)

3.3 *Water Budget Estimations for Future Climate Scenarios*

Table 3 shows the mean quotient between available resources and the precipitation (R/P; where R stands for “available resources” and P for “precipitation”) in the hydrological basins of the aquifers considered in this study using predictions for 2021 and 2050. The hydrologic balance considers predicted rainfall to estimate precipitation inputs, and predicted temperature and present land-use cover at a sub-basin scale to estimate the actual evapotranspiration. These R/P values are just representative of the direct recharge within the basin. Other recharge fluxes: stream inflow to the aquifer and regional flow systems, are not evaluated.

Nevertheless, a main difficulty at a basin level consists in separating between surface water and groundwater resources for the predicted values. In this sense, the average groundwater recharge values for the selected aquifers estimated by Alcalá and Custodio (2014) are also included in Table 3, and as they depend of soil conditions (which are assumed unchanged), groundwater recharge ratio (R(gw)/P) is assumed constant for 2021 and 2050.

4 Discussion

Based on the above data, climate change effects on groundwater quality are discussed based on the water balance approach and the learnings from the field work in the studied aquifers. We assume that for the next decades, major changes on land and groundwater uses will not occur unless any large development project is planned, which is the case in most these regional aquifers; yet, planned irrigation systems optimization and a potential reduction of nitrogen inputs would always contribute to reduce the fertilization impact.

4.1 Hydrological Concerns

As pointed out from climate predictions, water scarcity will primarily affect surface runoff and direct groundwater recharge. Surface runoff is relevant when discussing nitrate in alluvial aquifers, especially for loosing stream reaches, where runoff is the main input of low-nitrate content input to groundwater. In this sense, what does now constitute a recharge pole in the alluvial fluvio-deltaic aquifers of the Baix Ter and Baix Fluvià systems, it will reduce its contribution in the near future. If the consequences of diminishing discharge in the lower reaches of a river are to be examined, a set of outcomes can be enumerated. Explicitly, this implies several hydrological effects: (1) less aquifer recharge from the losing reaches, (2) less instream flow, (3) a diminution of the aquifer water table; and, (4) a reduction of the flow discharging back to the river in the gaining stream reaches. Direct groundwater recharge from rainfall will determine the rate and concentration to which nitrogen soil will percolate to the aquifer.

As regards to groundwater quality, a minor dilution associated with less stream and rainfall recharge will introduce nitrate to the soil, and later to the aquifer, at larger concentrations. In these circumstances, the overall hydraulic gradient will also be flattened due to a decrease of the inland hydraulic head at the boundaries, whether the stream itself or the surrounding hydrogeological, and an increase of the sea level. This will affect the alluvial aquifer residence time and, therefore, determine a longer stay of nitrate mass in the aquifer. Reduced outflows towards the stream or wetlands will reduce the rate of nitrogen assimilation that takes place in riparian areas. Denitrification processes will depend on the subsurface geochemical environment. Usual heterotrophic denitrification linked to the occurrence of organic matter and lack of oxygen, as observed in the Baix Ter area, can certainly be modified by soil production and oxygen solubility changes related to higher temperatures. Indeed, dry soil moisture lowers soil enzyme activity (Sardans et al. 2008), and increasing summer droughts will reduce mineralization and N and C fluxes whereas increasing summer precipitation could enhance losses (Borken and Matzner 2009). Nevertheless, nitrogen isotopes for the two alluvial aquifers (Baix Ter and Baix Fluvià) indicate that, under present conditions, only one out of four samples show some degree of denitrification. This suggests that nitrate mass may accumulate under future dominant hydrological conditions. Larger denitrification occurrence in Osona (nearly in a 30% of the samples) occur in marl deposits where pyrite oxidation enhances nitrate removal, and they are not associated with alluvial aquifers.

Alluvial aquifers in la Selva, Osona and Garrotxa hydrogeological systems are of less entity both in volume of groundwater storage and input/outflow magnitudes. Such smaller alluvial deposits will be even more depending on the stream discharge originated in the range headwaters.

From a management perspective, two actions can be adopted to minimize the effects of climate change. First, allocating wells in places and in aquifer levels more resilient to recharge variations. Secondly, reducing groundwater exploitation rates by increasing agricultural efficiency, urban water saving actions and diminishing losses in the distribution network, and ultimately, reclaim treated urban wastewater as an effective alternative to compensate water scarcity. Heavily urbanized areas with intense agricultural water demand are the first allocation places for treated wastewater, at least for specific uses as the total treated water volumes will be by far smaller than the agricultural demand. Presently, and more relevant under the future climatic scenarios, treated wastewater applied as irrigation will sum up its nitrogen content with that from applied manure, resulting in an excess load that will affect the final soil and groundwater nitrate concentration.

4.2 Environmental Concerns

In the effort to protect streams and wetlands as valued groundwater dependent ecosystems, water balance variations must be taken into consideration. Because of a diminishing recharge, nitrate mass will tend to accumulate in aquifers due, basically, to larger residence times caused by less inflow and minor outflow. Groundwater nitrate flowing to rivers in their gaining reaches or to wetlands may increase its content in surface water bodies. Nitrogen, as a nutrient, is highly assimilated by plants in riparian areas and pond boundaries, preventing eutrophication. Pumping rates will also interfere in hydrogeological dynamics. Capture zones affecting stream reaches and wetlands will progressively dry them up. Recovering natural flow fields after the irrigation season will feed the groundwater dependent stream reaches and wetlands with high-nitrate groundwater recharge. This is the reason why, especially in wetlands and ponds, preserving the natural habitat in their shores, where nitrogen assimilation/immobilization processes occur, is so essential.

4.3 Economic, Social and Political Concerns

Beyond hydrological and environmental concerns, climate change issues associated with nitrate pollution have strong economic and social sides. It is obvious that groundwater high nitrate concentrations are related to cattle rising (mainly pig) activities, being crucial for the economy of rural areas. Given the importance of this economic sector, it is not plausible that manure production will decrease in a medium run and, in consequence, arable lands will be fertilized at its maximum capacity to get rid of manures and slurries. As in any pollution case, input control is a key factor in controlling the spread and evolution of the pollutant. Alternative manure treatment processes should then be encouraged from the administration. In the context of climate change, as mentioned, lower recharge rates in the agricultural areas located on alluvial aquifers will hamper dilution. Hence, the management problem becomes twofold: water scarcity and pollution.

Solutions will need social and political support. From the social perspective, population, and politicians, need to understand the fact that under the new climatic scenarios the cost of good quality water resources will increase. From the socio-political side, education focused to recognize the value of a scarce resource should be focused not only to citizens, but also to farmers and, especially, first-sector investors whose profits are presently based on water resource exploitation strategies that would be unappropriated in the next decades. The livestock sector has to face it. From the political responsibility, a commitment is needed to impulse directives and measures focused on water resources planning that recognizes the urgency for actions. The water balance approach indicates that the "nitrate problem" may become even worse if the no-action attitude prevails. Active political involvement is paramount to force action and to adjust government as well as private responsibilities on preserving groundwater quality resources.

5 Conclusions

Under present nitrogen inputs in soils, groundwater nitrate concentration in the studied area will likely tend to increase/persist due to climate effects on the hydrologic cycle, land-use changes and human water demand. Recharge will be limited, and with it, its dilution capacity to decrease nitrate concentrations. Therefore, scientific-based opinions must be explained to stakeholders and decision makers so groundwater quality issues are included in their agendas together with water supply. Since agriculture is a primordial economical as well as territorial-integrating activity, and fertilization will necessarily go on, the nitrate-problem becomes twofold:

1. The implementation of better agricultural practices, yet their outcome is uncertain as seen from increasing local nitrate concentration tendencies despite the application of EU directives, mainly where livestock is the main economic activity.

2. New water supply alternatives must be sought and planned with time, so they can be appropriately programmed and executed, and their costs included in today's operational budgets so to avoid considering them as externalities when they will be urgently needed.

Acknowledgements This study is part of the REMEDIATION project (Spanish National Program on Water Resources; CGL2014-57215-C4-2-R), and also by the University of Girona fund MPCUdG2016/061.

References

Alcalá FJ, Custodio E (2014) Spatial average aquifer recharge through atmospheric chloride mass balance and its uncertainty in continental Spain. Hydrol Process 28:218–236

Borken W, Matzner E (2009) Reappraisal of drying and wetting effects on C and N mineralization and fluxes in soils. Glob Change Biol 15:808–824

Boy-Roura M, Nolan BT, Menció A, Mas-Pla J (2013) Regression model for aquifer vulnerability assessment of nitrate pollution in the Osona region (NE Spain). J Hydrol 505:150–162

Calbó J, Gonçalves M, Barrera Escoda A, García-Serrano J, Doblas-Reyes F, Guemas V, Cunillera J, Altava V (2016) Projeccions climàtiques i escenaris de futur. In: Martín Vide J (ed) Tercer Informe sobre el Canvi Climàtic a Catalunya. Pub. of Consell Assessor per al Desenvolupament Sostenible, pp 113–133

Fitts C (2012) Groundwater Science, 2nd edn. Academic Press, London

Folch A, Menció A, Puig R, Soler A, Mas-Pla J (2011) Groundwater development effects on different scale hydrogeological systems using head, hydrochemical and isotopic data and implications for water resources management: the Selva basin. J Hydrol 403:83–102

IPCC (2014) Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change, 151 p

Mas-Pla J, Batalla RJ, Cabello A, Gallart F, Llorens P, Pascual D, Pla E, Pouget L, Sànchez A, Termes M, Verbonyós L (2016) Recursos hidrològics. In: Martín Vide J (ed) Tercer Informe sobre el Canvi Climàtic a Catalunya. Pub. of Consell Assessor per al Desenvolupament Sostenible, pp 161–187

Menció A, Folch A, Mas-Pla J (2010) Analyzing hydrological sustainability through water balance. Environ Manag 45:1175–1190

Menció A, Mas-Pla J, Otero N, Soler A (2011) Nitrate as a tracer of groundwater flow in a fractured multilayered aquifer. Hydrol Sci J 56(1):108–122

Menció A, Mas-Pla J, Soler A, Otero N, Regàs O, Boy-Roura M, Puig R, Bach J, Domènech C, Folch A, Zamorano M, Brusi D (2016) Nitrate pollution of groundwater; all right …, but nothing else? Sci Total Environ 539C:241–251

Otero N, Torrentó C, Soler A, Menció A, Mas-Pla J (2009) Monitoring groundwater nitrate attenuation in a regional system coupling hydrogeology with multi-isotopic methods: the case of Plana de Vic (Osona). Agr Ecosyst Environ 133:103–113

Puig R, Folch A, Menció A, Soler A, Mas-Pla J (2013) Multi-isotopic study (15N, 34S, 18O, 13C) to identify nitrate evolution in a large-scale groundwater system. Appl Geochem 32:129–141

Puig R, Soler A, Widory D, Mas-Pla J, Otero N, Domènech C (2017) Characterizing sources and natural attenuation of nitrate contamination in the Baix Ter aquifer system (Spain) using a multi-isotope approach. Sci Total Environ 580:518–532

Sardans J, Peñuelas J, Estiarte M (2008) Changes in soil enzymes related to C and N cycle and in soil C and N content under prolonged warming and drought. Appl Soil Ecol 39:223–235

Stuart ME, Goody DC, Bloomfield JP, Williams AT (2011) A review of the potential impact of climate change on future nitrate concentrations in groundwater of the UK. Sci Total Environ 409:2859–2873

Zhang L, Dawes WR, Walker GR (2001) Response of mean annual evapotranspiration to vegetation changes at catchment scale. Water Resour Res 37:701–708