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Assessing the Expected Impact of Climate Change on Nitrate Load in a Small Atlantic Agro-Forested Catchment

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Additional information is available at the end of the chapter

Abstract

Climate change is likely to have profound impacts on quality of water resources, by altering the magnitude and timing of nutrient delivery to stream network. However, water quality responses to climate change are difficult to predict, especially for nutrient loads because of combined uncertainties in water quality and quantity projections. In this study, the potential medium (2031–2060) and long-term (2069–2098) impacts of project changes in climate variables (temperature, rainfall and CO_2 concentration) on nitrate load in an Atlantic agro-forested catchment (NW Spain) were assessed using the soil and water assessment tool (SWAT) model. Climate change scenarios are based on data projected by regional models from the ENSEMBLES project and two CO_2 concentration scenarios. The results showed that nitrate load will increase in the future horizons (2031–2060, 6%; 2069–2098, 7%) in relation to current values (1981–2010), possibly due to the decline in grassland biomass, as well as an increase in the rate of mineralisation linked to the increase in temperature. Consequently, lower rates of fertilisers will be needed in these areas in future horizons, which should be taken into consideration when planning management strategies in order to mitigate the impacts of potential climate change.

Keywords: nitrate, climate change, SWAT model, agro-forested catchment

1. Introduction

Nitrogen (N) is a key nutrient in river systems. Its concentration and form in the aquatic environment generally reflect the integration of a number of sources within the catchment including point and/or nonpoint sources. In addition to these anthropogenic contributions, there are "natural" contributions from the mineralisation and nitrification of organic nitrogen in soils [1]. Within aquatic environments, nitrate (NO_3) is generally the dominant N fraction due to high NO_3 mobility in the environment [2], as a result of its persistence, high solubility and low reactivity. The N problem, due to the excessive application of fertilisers for crop production, has been of growing concern in recent decades as it affects the water quality for consumption, promotes the development of eutrophication and reduces biodiversity [3, 4].

Changes in the climatic conditions and, particularly, increases in air temperature, shifts in rainfall patterns and an increase in the frequency of flood and droughts alter the processes controlling the mobilisation and transfer of N from agricultural land to aquatic ecosystems [5–7]. Rising water temperatures influence biological processes and chemical characteristics of water resources, e.g. increasing the mineralisation of organic matter, decreasing oxygen solubility, increasing the variability in pH values and increasing growth rates of aquatic organisms. A lower water availability might affect the quality of surface water resources adversely and even have a significant negative impact on human health and the economic development of the entire region [7, 8].

Since protecting and restoring the aquatic ecosystem is a policy priority in Europe [9], catchment management planning should focus on adaptively managing climate change impacts, although climate change is not explicitly included in the European Water Framework Directive (WFD), because climate change is expected to have profound effects on water resources and water quality [10]. The facts show that effects of climate change have not been properly addressed in policy formulation and water resource management strategies in many regions around the world, probably due to the lack of accurate and reliable data on the possible effects of climate change on water resources. Nitrogen pollution is already considered as a global problem [11], and it is expected that N loss will aggravate in vulnerable areas due to climate change [5, 8]. For this, it is of upmost importance to assess and quantify the impacts of climate change and vulnerability of water resources and evaluate the efficiency of possible adaptation and mitigation policies.

While many researches in different study areas assessed the climate change impacts on catchment hydrology and water supply, water quality has been studied much less [6, 12–14]. So, little is known about the potential effects of climate change on biogeochemical processes at catchment scale and its associated impacts on water quality. So far, very few studies have addressed the water resource on the Atlantic region of Europe, and, consequently, little is known about the effects of climate change in water quality in this area. This can constitute a challenge because hydrological processes in this region will change in response to climate change [15–17], as they are expected to undergo a Mediterranization process. In fact, in the northwest of Iberian Peninsula, an increase in temperatures (2–3°C) is expected, particularly during spring and summer, with marked uneven distribution of rainfall, i.e. more rain in autumn but drier spring and summer [18]. Likewise, according to the Intergovernmental Panel on Climate Change [19], climate change will cause an increase in the future winter storm and flooding for the Atlantic region of Europe, which encompasses northern Iberian

Peninsula, western France, the Netherlands, Belgium, northern part of Germany, western Denmark and the United Kingdom. Uncertainties involved in climate predictions are larger in this transition zone of the Atlantic region than in other areas, e.g. the northern and the southern parts of the continent. Therefore, this transition zone should be an in-depth studied area.

This paper provides an overview of the effects of changes in climate on nitrate loads in NW Spain. Specifically, the main objective of this study was to assess the impacts of the potential changes in climate variables (temperature, rainfall and CO_2 concentration) on nitrate load in an Atlantic agro-forested headwater catchment located in NW Spain using the SWAT model (one of the most widely used catchment models throughout the world) in order to provide information to catchment management so that they can anticipate possibly the impact on water quality and design and implement the necessary mitigation actions within the catchment management programs.

2. Study area characterisation

The Corbeira catchment is located in the headwater of the Mero basin, at about 30 km from the city of A Coruña in NW SPain (**Figure 1**). The catchment covers an area of 16 km². Elevations range from 65 to 470 m a.s.l., with a mean slope of 19%. The geological substrate is
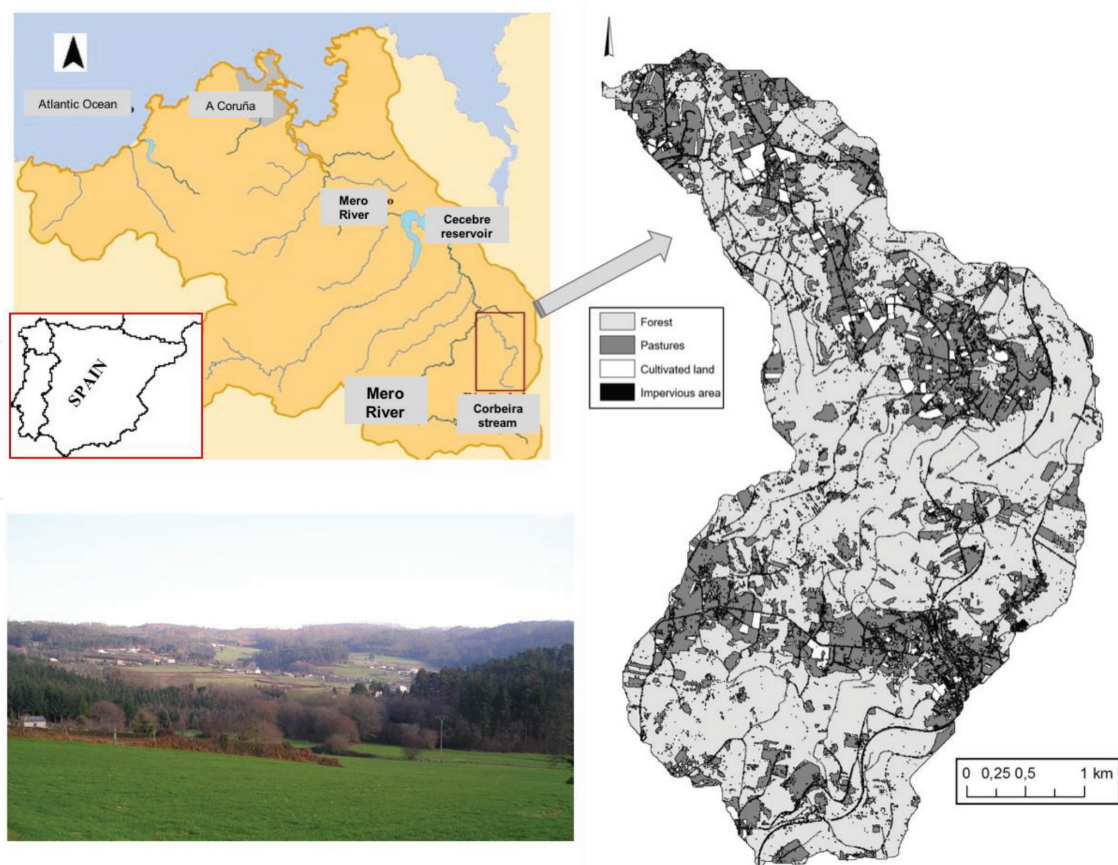

Figure 1. Location of the study area, general view of the Corbeira catchment and land-use map.

dominated by the basic schist of the Órdenes Complex [20], and the main soil types present in the catchment are umbrisol and cambisol [21], which represent 74 and 25%, respectively. Predominating land use is a forest covering 65% of the catchment area, followed by pasture (26%), impervious areas (5%) and cultivated land (4%). The population density in the catchment is low (35 inhabitants km^{-2}); there are no industries, and human activities are reduced to rural traditional agriculture and livestock (0.29 LU ha^{-1}).

The mean annual temperature is about 13°C, with mean annual minimum and maximum temperatures of 8.6 (February) and 18.4°C (July), respectively. The mean annual rainfall is about 1170 mm, more than 65% occurring between October and March. The annual mean flow rate is 0.18 m^3 s^1, and it is mainly supplied by groundwater. For more information of the study area, see Rodríguez-Blanco et al. [22–24].

3. Methodology

3.1. Model description

The SWAT model was developed by the Agricultural Research Service of the US Department of Agriculture (USDA) to quantify and predict the impact of agricultural management practices on water, sediment and agricultural chemical in large complex catchments [25, 26], although is has been satisfactorily applied in small catchments all over the world [10, 14–16]. It is a continuous, distributed model, although not completely distributed, since it does not use cells but divides the basin into sub-basins that are further divided into Hydrological Response Units (HRUs). For this reason, sometimes it is defined as semi-distributed. It is based on physical principles to describe the relationship between the input and output variables. It needs specific data from the catchment (climate, physical properties of the soil, topography, vegetation, soil management practice, etc.), which are used to model physical processes related to the movement of water and sediments, growth of crops and nutrient cycles. SWAT simulations can be separated into two components, the land phase for water and pollutants loadings to channels and the routing phase for in-stream water quantity and quality. Regarding nitrogen, the model simulates N transport and transformation at HRU scale; considering the processes of denitrification, volatilisation and organic N, stable organic N associated with humic substances and fresh organic N associated with the crop residues are distinguished. Nitrate can be transported from land to stream network via surface runoff, lateral flow and groundwater flow. A more detailed description of the SWAT model can be found in [25, 26]

3.2. Climate change scenarios

Reseach into the impact of climate in the future has focused on evaluating the effects that change in temperature, rainfall and CO_2 concentration might cause on nitrate load, following the methodology used in [15, 27]. Two simulation sets were used: one evaluated the response of the catchment to changes in single-climate variables (temperature, rainfall or CO_2 concentrations) and the other one assessed the impact caused by simultaneous changes in temperature, rainfall or CO_2 concentrations. In total, 14 different climate change scenarios were used (**Table 1**).

Scenario	Modified parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	T (°C)	1.0	0.9	0.7	0.9	1.1	1.0	1.3	1.5	1.4	1.2	1.0	1.4
2	T (°C)	1.6	1.5	2	1.7	1.9	2.1	2.5	2.7	2.4	2.8	1.6	2.3
3	T (°C)	1.8	1.6	1.6	1.7	2.2	2.5	2.6	3.0	2.7	2.5	2.2	2.2
4	(°C)	2.7	3.2	3.2	2.9	3.8	4.7	4.5	4.9	5.5	5.0	3.7	2.9
5	P (mm)	−1.2	1.0	−5.2	−12.7	−10.6	−11.4	−9.8	−11.8	−6.8	−8.2	−8.7	17.8
6	P (mm)	−26.0	−28.3	−12.9	−30.4	−15.5	−24.1	−17.2	−23.9	−30.7	−46.4	−37.9	54.7
7	P (mm)	−3.5	−1.0	−5.2	−17.6	−31.8	−21.0	−14.5	−16.4	−19.1	−27.4	−8.7	−8.9
8	P (mm)	36.6	17.2	−22.4	−26.5	−37.5	−30.2	−20.6	−28.5	−28.0	−56.1	−56.8	−29.6
9	CO$_2$ (ppm)	550	550	550	550	550	550	550	550	550	550	550	550
10	CO$_2$ (ppm)	660	660	660	660	660	660	660	660	660	660	660	660
11	T (°C)	1.0	0.9	0.7	0.9	1.1	1.0	1.3	1.5	1.4	1.2	1.0	1.4
	P (mm)	−1.2	1.0	−5.2	−12.7	−10.6	−11.4	−9.8	−11.8	−6.8	−8.2	−8.7	17.8
	CO$_2$ (ppm)	550	550	550	550	550	550	550	550	550	550	550	550
12	T (°C)	1.6	1.5	2	1.7	1.9	2.1	2.5	2.7	2.4	2.8	1.6	2.3
	P (mm)	−26.0	−28.3	−12.9	−30.4	−15.5	−24.1	−17.2	−23.9	−30.7	−46.4	−37.9	54.7
	CO$_2$ (ppm)	550	550	550	550	550	550	550	550	550	550	550	550
13	T (°C)	1.8	1.6	1.6	1.7	2.2	2.5	2.6	3.0	2.7	2.5	2.2	2.2
	P (mm)	−3.5	−1.0	−5.2	−17.6	−31.8	−21.0	−14.5	−16.4	−19.1	−27.4	−8.7	−8.9
	CO$_2$ (ppm)	660	660	660	660	660	660	660	660	660	660	660	660
14	T (°C)	2.7	3.2	3.2	2.9	3.8	4.7	4.5	4.9	5.5	5.0	3.7	2.9
	P (mm)	36.6	17.2	−22.4	−26.5	−37.5	−30.2	−20.6	−28.5	−28.0	−56.1	−56.8	−29.6
	CO$_2$ (ppm)	660	660	660	660	660	660	660	660	660	660	660	660

Notes: Scenario 1, T + mean 2031–2060 C; Scenario 2, T + max 2031–2060 C; Scenario 3, T + mean 2069–2098 C; Scenario 4, T + max 2069–2098 C; Scenario 5, P − mean 2031–2060%; Scenario 6, P − max 2031–2060%; Scenario 7, P − mean 2069–2098%; Scenario 8, P − max 2069–2098%; Scenario 9, 1.5 × CO$_2$; Scenario 10, 2 × CO$_2$; Scenario 11, Scenario 1 + Scenario 5 + Scenario 9; Scenario 12, Scenario 2 + Scenario 6 + Scenario 10; Scenario 13, Scenario 3 + Scenario 7 + Scenario 9; and Scenario 14, Scenario 4 + Scenario 8 + Scenario 10.

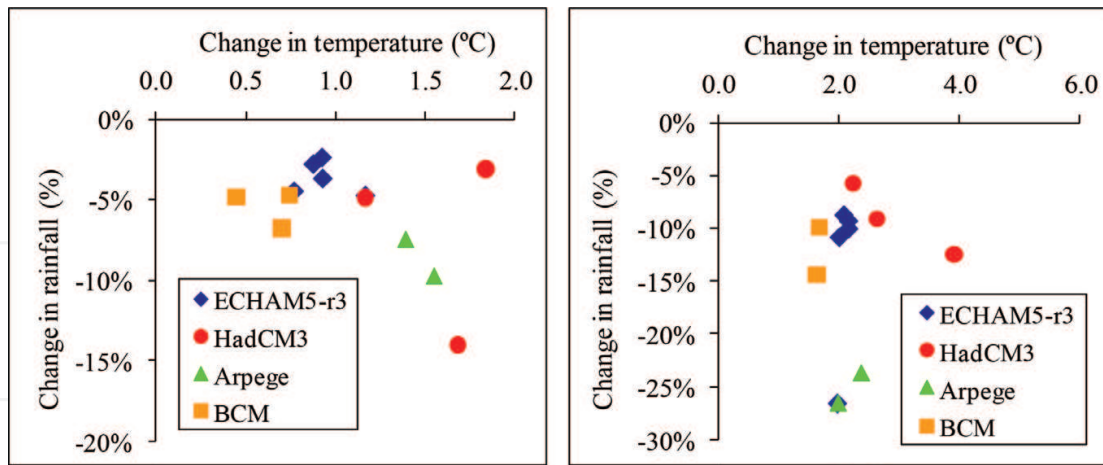**Table 1.** Climate change scenarios used in the simulations.

Figure 2. Variation range of forecast mean annual temperature and rainfall (ENSEMBLES project) for (a) period 2031–2060 and (b) period 2069–2098. Symbols identify different global models.

The different climatic scenarios used in this study are based on predicted future alterations from regional models in the ENSEMBLES project (socio-economic A1B scenario) for the closest meteorological station of the study area, for the periods 2031–2060 and 2069–2098. Due to variability of projections of future temperature and rainfall among the different models (**Figure 2**), the data from the models were combined to obtain the mean and maximum monthly rainfall and temperature for two periods: 2031–2060 (intermediate future) and 2069–2098 (distant future). Differences between projected and current values for the reference period (1981–2010) were used to develop the climate scenarios.

The stochastic weather generator has proven to be a useful tool for generating climate data series of high spatial and temporal resolutions to be used in climate change impact studies. In this study, the WXGEN weather generator included in the SWAT model was used to produce 30 years of synthetic daily weather data series for each climate change scenario, following the methodology used in [15, 17]. These weather data were used to run the SWAT model to simulate nitrate load under different climate change scenarios.

The nitrate load yields under the selected scenarios were compared with the 30-year simulation of the reference period. T-tests were conducted to determine the significance of the difference in nitrate load between the reference scenario and the climate change scenarios. All of the statistical tests were performed in PASW Statistics 18 for the Windows program package (SPSS Inc.) at a significance level of 0.05.

4. Results and discussion

4.1. Use of WXGEN weather

The SWAT model was previously calibrated and validated for streamflow, suspended sediment and nitrate yield in the study area [15, 27, 28]. Regarding the nitrate, it pointed out the importance of agricultural land (30% of catchment area) as the main contributor to N losses (77%),

which reach the stream mainly in groundwater flow. The estimated yield (4.8 kg ha^{-1}) showed a close value to the measured values (5.1 kg ha^{-1}). Nash-Sutcliffe efficiency >0.50 and percent bias <10% were obtained during the calibration and validation period, indicating that the model was able to simulate the nitrate yield in the research area [28]. So, it was considered suitable for study of the impact of climate change on nitrate load in the catchment study.

The utility of the WXGEN weather generator embedded in the SWAT model was tested with the objective of assessing its use in simulations of climate scenarios. For this, the model was run using the climate generator for current conditions (reference period 1981–2010) to simulate nitrate load. Then, these results were compared with simulated nitrate load estimated using observed meteorological data. The statistical indicators (R^2 = 0.60 and NSE = 0.55), according to the criteria proposed by Refs. [29, 30], suggest a satisfactory model performance and indicate that the WXGEN weather generator can be used with a reasonable degree of confidence reasonable to analyse climate change scenarios in the study area.

4.2. Impacts of changes in temperature, rainfall and CO_2 concentrations in nitrate load

An increase in the nitrate load is predicted, both increasing in temperature and CO_2 concentrations, while a decrease was forecast for scenarios with reductions in rainfall (**Table 2**). The variation in the nitrate load in future scenarios is lower than that foreseen for streamflow and suspended sediment [15, 27], indicating thta it is less sensitive to changes in rainfall, temperature and CO_2 concentration than to discharge and sediment. The forecast pattern of nitrate load is similar to that streamflow, except in scenarios with changes in rainfall, as frequently

	NO$_3$ yield (kg ha^{-1} y^{-1})	Percentage of change	NO$_3$ concentration (mg L^{-1})
Reference period (1981–2010)	4.66		8.09
Scenario 1	4.89	5	9.71
Scenario 2	4.99	7	11.34
Scenario 3	5.01	8	12.28
Scenario 4	5.16	11	15.89
Scenario 5	4.67	0	9.18
Scenario 6	4.53	−3	10.70
Scenario 7	4.53	−3	10.71
Scenario 8	4.31	−7	15.06
Scenario 9	4.71	1	7.51
Scenario 10	4.75	2	7.18

Temperature (Scenarios 1–4), rainfall (Scenarios 5–8) and CO_2 concentration (Scenarios 9 and 10) based on scenarios defined in **Table 1**.

Table 2. Response of nitrate yield and concentration to changes in climate variables.

reported in the literature [12–14, 31], although this does not always happen. For example, Ficklin et al. [6] when analysing the sensitivity of nitrate load to increased CO_2 concentrations observed a decrease in nitrate yield linked to increased streamflow.

Since the entry of fertilisers into the simulations remained constant in relation to reference conditions, the forecast increase in nitrate load with increasing temperature is probably due to a greater contribution of N from agricultural areas, because of the decrease in plant biomass of grasslands and crops [15] with increasing temperature, as well as to the increase in organic nitrogen mineralisation. The N mineralisation in the soil depends on the nature and abundance of organic matter and temperature, humidity and pH and microbial activity. It is well known that it increases with the content of organic matter and temperature [32], which leads to an accumulation of inorganic nitrogen in the soil and an increased risk of leaching [33], provided that the water content does not limit the microbial activity [34]. In the study area, the annual rainfall is 1141 mm (1983/1984–2016/2017) so the water content of the soil should not be limiting for microbial activity, and, therefore, the increase of temperature could accelerate the transformation of nitrogen from organic to inorganic forms. Other authors, such as Ref. [31] in the Yorkshire river basin (the United Kingdom) and Ref. [14] in the Assiniboine basin (Canada), also attributed the increase in nitrate load to the accelerated mineralisation of biomass, although in all these cases, the nitrate followed the same trend as the streamflow.

The effects of climate variables on nitrate load were more noticeable on a seasonal level (**Figure 3**), highlighting the role of seasonal climate variations in affecting future nitrate. When changes in temperature were included, nitrate yield was forecast to rise in all seasons except summer, with the largest load increases in winter. These differences could be due to the increase of mineralisation in summer, with the consequent retention of nitrates in the soils because of the lack of water to transport them, while in the rainy seasons, the transport will be favoured, so it is more likely that load increases. Ref. [35] in laboratory experiences, carried out, therefore, with an artificial heating (heating, greenhouses), reported an increase in net mineralisation rates of 46%, while Ref. [36] when analysing the impact of climate change on quality of water in the Seine River (France) found an increase of between 8% and 26% in the net rate of mineralization.

When rainfall is modified, an increase in the nitrate load is expected in winter and a decline in the other seasons, especially in autumn, although the increase in winter does not compensate the losses in the other stations.
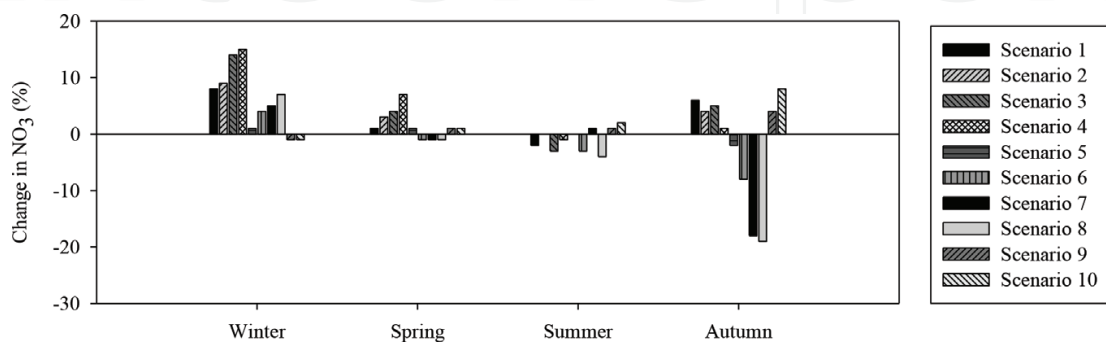

Figure 3. Seasonal response of nitrate load to changes in temperature (Scenarios 1–4), rainfall (Scenarios 5–8) and CO_2 concentrations (Scenarios 9 and 10) based on the scenarios defined in **Table 1**.

The results obtained at seasonal scale point out that the differences between seasons are attenuated for those scenarios that consider annual anomalies (e.g. Scenarios 3 and 4). This reveals that the scenarios that consider a certain exchange rate of temperature and/or rainfall, frequently used in the evaluation of impact of climate change on water resources and water quality, show the impacts on an annual scale but will hardly report processes that occur at smaller scales, because they do not take into account the distribution of temperatures and rainfall throughout the year, being necessary studies at seasonal scales.

4.3. Impacts of simultaneous changes in climate variables on nitrate load

Climate change is expected to increase the nitrate load in the Corbeira catchment (**Table 3**). This fact has been frequently attributted to greater water discharge [13, 14, 30]; however, Corbeira behaves differently in that there is an increase in nitrate load and a reduction in river flows, which shows that the streamflow will not be the determining factor of the nitrate load in this catchment in future scenarios. This contrast with the results of other studies in the Iberian Peninsula [12, 37], which reported reductions in N exports due to the decrease of streamflow.

The simulations performed with the average anomalies (Scenarios 11 and 13, **Table 1**) forecast an increase in the nitrate load in the order of 6% for the period 2031–2060 and 7% for the horizon 2069–2098, reflecting a great similarity for the entire twenty-first century, despite the notable differences expected in the streamflow, which will decrease by 16 and 35% at the mid and end of the twenty-first century [15]. An increase in the nitrate load during the spring and, especially, during the winter, which will be able to counteract the expected losses during the summer and autumn seasons (**Figure 4**), is observed. This behaviour could be related to an increased activity of the enzymes of the soil in the stations with greater water availability, as indicated by [38].

In general, nitrate losses depend on the hydrological balance, the quantities present in the soil (both from natural inputs and fertilisation) and the degree to which they are absorbed by vegetation [39]. It is known that rising temperatures and droughts exert a great influence on nutrient dynamics, since the warming increases mineralisation and drought prevents the absorption of nutrients from the plants and facilitates losses to the system when the rains arrive. The increase in the nitrate load with climate change, in this catchment, could be related to an increase in mineralisation and with the decreased nitrate absorption by

	NO_3 yield (kg ha^{-1} y^{-1})	Percentage of change	NO_3 concentration (mg L^{-1})
Reference period (1981–2010)	4.66		8.09
Scenario 11	4.94	6	10.16
Scenario 12	4.97	7	9.52
Scenario 13	4.97	7	20.12
Scenario 14	5.02	8	23.15

Table 3. Response of nitrate load to combined changes in temperature, rainfall and CO_2 concentrations based on the scenarios defined in **Table 1**.
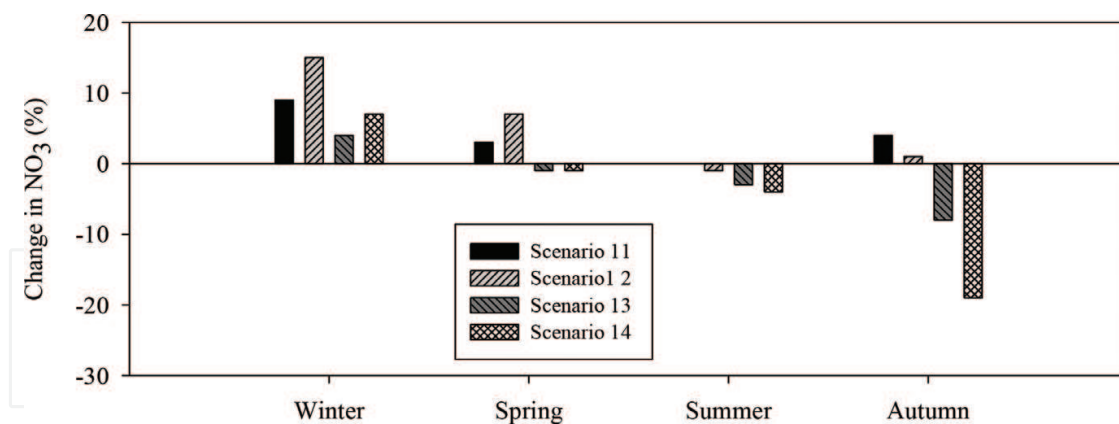
Figure 4. Seasonal response of nitrate load to combined changes in temperature, rainfall and CO_2 concentrations based on the scenarios defined in **Table 1**.

vegetation. A reduction in nitrate absorption is predicted for all land uses, especially significant in prairie areas (15% for the period 2031–2060 and 22% for 2069–2098). This points to less fertilizer being needed in these areas, which should be taken into consideration when planning management strategies in order to mitigate the impacts of potential climate change.

Despite the increase in nitrate concentration with climate change, the figures expected by the end of the twenty-first century would be well below the limits established by the current legislation for water for human consumption [40], so the supposed increase would be of concern for limitation for the human consumption, although it would result in degraded water quality.

The effects of land use have not been addressed in this study, since it was restricted to investigating the impacts of climate change on nitrate load because there is generally more uncertainty in climate projection than land use. So, more attention should be given to investigating the impacts due to climate change rather than land-use change. However, the effect of future land use on future nitrate load is controversial [10, 37, 39]. Some authors indicated that the effect of land cover is more visible than the climate change effect [37], while others found that stream nitrate concentrations were much more impacted by climate change than land-cover changes [10, 39]. This highlights the need to understand the combined effect of changes in land use and climate on catchment nitrogen discharge. This issue will be the aim of further research into modelling the water quality in the catchment study.

5. Summary and conclusions

This study was carried out to determine the effects of climate change on nitrate load in an agro-forested catchment located in NW Spain using the WXGEN weather generator included in the SWAT model. The results suggested that the WXGEN generator was able to adequately estimate long-term nitrate load.

Overall, it is verified that the nitrate load will increase in the future horizons in relation to current values (about 6 and 7% for the periods 2031–2060 and 2069–2098, respectively), possibly due to the decline in grassland biomass, as well as an increase in the rate of mineralisation

linked to the increase in temperature. A higher rate of mineralisation of organic matter will result in the released nitrate being dragged by the water towards the fluvial course. Despite this, the concentrations of nitrates planned for the end of the twenty-first century would be well below the limits established by the current legislation in force for drinking water, so the supposed increase would not be a limitation for human consumption, although a deterioration in the quality of water in the study area is expected.

Acknowledgements

Conflict of interest

The authors declare no conflict of interest.

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References

[1] Wade A, Soulsby C, Langan SJ, Whitehead PG, Edwards AG, Butterfield D, et al. Modelling in stream nitrogen variability in the Dee catchment, NE Scotland. The Science of the Total Environment. 2001;**265**:229-252. DOI: 10.1016/S0048-9697(00)00661-6

[2] Kolenbrander GJ. Leaching of nitrogen in agriculture. In: Brogan JC, editor. Nitrogen Losses and Surface Runoff from Land Spreading of Manures. The Hague: Martinus Nijhoff; 1982. pp. 199-216

[3] Camargo JA, Alonso A, Salamanca A. Nitrate toxicity to aquatic animals: A review with new data for freshwater invertebrates. Chemosphere. 2005;**58**:1255-1267. DOI: 10.1016/j.chemosphere.2004.10.044

[4] Dupas R, Jomaa S, Musolff A, Borchardt D, Rode M. Disentangling the influence of hydroclimatic patterns and agricultural management on river nitrate dynamics from sub-hourly to decadal time scales. The Science of the Total Environment. 2016;**15**:791-800. DOI: 10.1016/j.scitotenv.2016.07.053

[5] Bindi M, Olesen JE. The responses of agriculture in Europe to climate change. Regional Environmental Change. 2010;**11**:151-158. DOI: 10.1007/s10113-010-0173-x

[6] Ficklin DL, Luo Y, Luedeling E, Gatzke SE, Zhang M. Sensitivity of agricultural runoff loads to rising levels of CO_2 and climate change in the San Joaquin Valley watershed of California. Environmental Pollution. 2010;**158**:223-234. DOI: 10.1016/j.envpol.2009.07.016

[7] Whitehead PG, Wilby RL, Battarbee RW, Kernan M, Wade AJ. A review of the potential impacts of climate change on surface water quality. Hydrological Sciences. 2012;**54**: 101-123. DOI: 10.1623/hysj.54.1.101

[8] Zessner M, Schönhart M, Parajka J, Trautvetter H, Mitter H, Kirchner M, et al. A novel integrated modelling framework to assess the impacts of climate and socio-economic drivers on land use and water quality. The Science of the Total Environment. 2017;**579**:1137-1151. DOI: 10.1016/j.scitotenv.2016.11.092

[9] EC. Directive 2000/60/EC of the European parliament and of the council of 23 October 2000 establishing a framework for community action in the field of water policy. Official Journal of the European Communities. 2000;**22**:72 L 327/1

[10] Gabriel M, Knightes C, Cooter E, Dennis R. Evaluating relative sensitivity of SWAT-simulated nitrogen discharge to projected climate and land cover changes for two watersheds in North Carolina, USA. Hydrological Processes. 2016;**30**:1403-1418. DOI: 10.1002/hyp.10707

[11] Steffen W, Richardson K, Rockström J, Cornell SE, Fetzer I, Bennett EM, et al. Planetary boundaries: Guiding human development on a changing planet. Science. 2015;**347**: 1259855-1-1259855-10. DOI: 10.1126/science.1259855

[12] Molina-Navarro E, trolle D, Martínez-Pérez S, Sastre-Merlín A, Jeppesen E. Hydrological and water quality impact assessment of a Mediterranean limno-reservoir under climate change and land use management scenarios. Journal of Hydrology. 2014:354-366. DOI: 10.1016/j.jhydrol.2013.11.053

[13] Martinkova M, Hesse C, Krysanova V, Vetter T, Hanel M. Potential impact of climate change on nitrate load from the Jizera catchment (Czech Republic). Physics and Chemistry of the Earth. 2011;**36**:673-683. DOI: 10.1016/j.pce.2011.08.013

[14] Shrestha RR, Dibike YB, Prowse T. Modeling climate change impacts on hydrology and nutrient loading in the upper Assiniboine catchment. Journal of the American Water Resources Association. 2011;**48**:74-89. DOI: 10.1111/j.1752-1688.2011.00592.x

[15] Arias R, Rodríguez-Blanco ML, Taboada-Castro MM, Nunes JP, Keizer JJ, Taboada-Castro MT. Water resources response to changes in temperature, rainfall and CO_2 concentration: A first approach in NW Spain. Water. 2014;**6**:3049-3067. DOI: 10.3390/w6103049

[16] Zabaleta A, Meaurio M, Ruiz E, Antigüedad I. Simulation climate change impact on runoff and sediment yield in a small watershed in the Basque Country, northern Spain. Journal of Environmental Quality. 2014;**43**:235-245. DOI: 10.2134/jeq2012.0209

[17] Meaurio M, Zabaleta A, Boithias L, Epelde AM, Sauvage S, Sánchez-Pérez JM, et al. Assessing the hydrological response from an ensemble of CMIP5 climate projections in the transition zone of the Atlantic region (Bay of Biscay). Journal of Hydrology. 2017;**548**:46-62. DOI: 10.1016/j.jhydrol.2017.02.029

[18] Álvarez V, Taboada JJ, Lorenzo MN. Cambio climático en Galicia en el siglo XXI: Tendencias y variabilidad en temperaturas y precipitaciones [Climate change in Galicia by the XXI century: Tendencies and variability in temperatures and precipitation]. Revista Avances Ciencias Terra (ACT). 2011;**2**:65-85

[19] IPCC (International Panel of Climate Change). Climate Change 2007: Synthesis report. In: Core Writing Team, Pachauri RK, Reisinger A, editors. Contribution of working groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change; Geneva. 2007. 103 p

[20] Instituto Tecnológico Geominero de España (IGME). Mapa Geológico de España, 1:50,000. Hoja 45. Madrid, Spain: Betanzos; Servicio de Publicaciones del Ministerio de Industria y Energía; 1981

[21] IUSS Working Group WRB. World Reference Base for Soil Resources 2014, Update 2015. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps; World Soil Resources Reports No. 106. Rome, Italy: FAO; 2015

[22] Rodríguez-Blanco ML, Taboada-Castro MM, Palleiro L, Taboada-Castro MT. Temporal changes in suspended sediment transport in an Atlantic catchment, NW Spain. Geomorphology. 2010;**123**:181-188. DOI: 10.1016/j.geomorph.2010.07.015 479

[23] Rodríguez-Blanco ML, Taboada-Castro MM, Taboada-Castro MT. Rainfall runoff response and event based runoff coefficients in a humid area (northwest Spain). Hydrological Sciences Journal. 2012;**57**:445-459. DOI: 10.1080/02626667.2012.666351 476

[24] Rodríguez-Blanco ML, Taboada-Castro MM, Taboada-Castro MT. Linking the field to the stream: Soil erosion and sediment yield in a rural catchment NW Spain. Catena. 2013; **102**:74-81. DOI: 10.1016/j.catena.2010.09.003

[25] Arnold JG, Srinivasan R, Muttiah RS, Williams JR. Large area hydrologic modeling and assessment. Part I: Model development. Journal of the American Water Resources Association. 1998;**34**:73-89. DOI: 10.1111/j.1752-1688.1998.tb05961.x

[26] Neitsch SL, Arnold JG, Srinivasan R, Williams JR. Soil and Water Assessment Tool User's Manual. TX, USA: Texas Water Resources Institute: Colleague Station; 2002. 506 p

[27] Rodríguez-Blanco ML, Arias R, Taboada-Castro MM, Nunes JP, Keizer JJ, Taboada-Castro MT. Potential impact of climate change on suspended sediment yield in NW Spain: A case study on the Corbeira catchment. Water. 2016;**8**:444. DOI: 10.3390/w8100444 www.mdpi.com/journal/water

[28] Rodríguez-Blanco ML, Arias R, Taboada-Castro MM, Nunes JP, Keizer JJ, Taboada-Castro MT. Modelling the contribution of land use to nitrate yield from a rural catchment. Landscape Ecology. 2016;**I**:27-28. DOI: 10.5772/63718

[29] Motovilov Y, Gottschalk GL, Engeland K, Rodhe A. Validation of distributed hydrological model against spatial observations. Agricultural and Forest Meteorology. 1999;**98**: 257-277. DOI: 10.1016/S0168-1923(99)00102-1

[30] Moriasi DN, Arnold JG, van Liew MW, Bingner RL, Harmel RD, Veith TL. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Translations ASABE. 2007;**50**:885-900. DOI: 10.13031/2013.23153

[31] Bouraoui F, Galbiati L, Bidoglio G. Climate change impacts on nutrient loads in the Yorkshire Ouse catchment (UK). Hydrology and Earth System Sciences. 2002;**6**:197-209. DOI: 10.5194/hess-6-197-2002

[32] Leirós MC, Trasar-Cepeda C, Seoane S, Gil-Sotres F. Dependence of mineralization of soil organic matter on temperature and moisture. Soil Biology and Biochemistry. 1999;**31**: 327-335. DOI: 10.1016/S0038-0717(98)00129-1

[33] Olesen JE, Bindi M. Consequences of climate change for European agricultural productivity, land use and policy. European Journal of Agronomy. 2002;**16**:239-262. DOI: 10.1016/S1161-0301(02)00004-7

[34] Zak DR, Holmes WE, MacDonald NW, Pregitzer KS. Soil temperature, matric potential, and the kinetics of microbial respiration and nitrogen mineralization. Soil Science Society of America Journal. 1999;**63**:575-584. DOI: 10.2136/sssaj1999.03615995006300030021x

[35] Rustad LE, Campbell JL, Marion GM, Norby RJ, Mitchell MJ, Hartley AE. A meta-analysis of the response of soil respiration, net nitrogen mineralization, and aboveground plant growth to experimental ecosystem warming. Oecologia. 2001;**126**:543-620. DOI: 10.1007/s004420000544

[36] Ducharne A, Baubion C, Beaudoin N, Benoit M, Billen G, Brisson N. Long term prospective of the Seine River system: Confronting climatic and direct anthropogenic changes. The Science of the Total Environment. 2007;**375**:292-311. DOI: 10.1016/j.scitotenv.2006.12.011

[37] Carvalho-Santos C, Nunes JP, Monteiro AT, Heins L, Honrado JP. Assessing the effects of land cover and future climate conditions on the provision of hydrological services in a medium sized watershed of Portugal. Hydrological Processes. 2016;**30**:720-738. DOI: 10.1002/hyp.10621

[38] Sardans J, Peñuelas J, Estiarte M. Changes in soil enzymes related to C and N cycle and in soil C and N content under prolonged warming and drought in a Mediterranean shrubland. Applied Soil Ecology. 2008;**39**:223-235

[39] Ferrier RC, Whitehead PG, Sefton C, Edwards AC, Puhg K. Modeling impacts of land use change and climate change on nitrate nitrogen in the River Don, North East Scotland. Water Research. 1995;**29**:1950-1956

[40] European Council. Directive 75/440/CEE of the 16 June 1975 for provision of water to provide potable water. Official Journal of the European Union L. 1975;**194**:26