GROUNDWATER NITRATES POLLUTION AND CLIMATE CHANGE

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ABSTRACT

This paper reviews the potential impacts of climate change on nitrate concentrations in groundwater in the Mediterranean region and in Greece in particular. The foreign and Greek literature was reviewed, with the aim of examining all the factors and parameters involved in the formation and leaching of nitrates from the soil to groundwater and to give special basis to the possible effects of climate change in the above process. To assess the impact of climate change on future concentrations of nitrates in groundwater, in the Mediterranean region and in Greece, a Source-Pathway-Receptor model was applied to the nitrogen (N) cycle. Climate change will affect both soil and N cycle processes, as well as agricultural productivity. For Southern Europe and the Mediterranean region climate change is expected to negatively affect agricultural production. Climate change will also affect the hydrological cycle, with changes in recharge, groundwater levels and resources, and flow processes. The predicted effects are variable, but indicate an overall decrease in recharge and a drop in water level, with an increased seasonal variation of water levels between wet and dry periods. This will affect nitrate concentrations in the recoverable water and other potentially more sensitive receptors, such as groundwater-dependent wetlands, on an annual basis. Nitrate leaching is likely to increase in the future if changes in agricultural practices are not made. Future impacts may also be driven by economic responses to climate change.

KEYWORDS

Climate change; Groundwater; Mediterranean; Nitrate; Pollution; Source-Pathway-Receptor

1. INTRODUCTION

Groundwater is an important natural resource, with great economic, social and environmental value. Modern agricultural systems, which began to be applied in the mid-twentieth century, with monoculture and large-scale animal husbandry, were based on the extensive use of inorganic fertilizers, which led to a large increase in yield and production, but also to pollution of groundwater, as a result of the reckless use of these inputs. Groundwater pollution with nitrate ions is very important, due to its widespread presence in groundwater aquifers worldwide and the potential impact it may have on human, animal and environmental health.

Inputs of N, in various forms, contribute to the stock of organic N in the soil, while a series of bacterial-mediated transformations are required to convert the various organic and inorganic forms of N to nitrates, which can potentially be leached into the groundwater. The processes involved in transporting various N compounds, including nitrate ions into the geoenvironment are complex and are directly related to factors, such as seasonality and climate, soil properties and land uses [1].

In this paper an attempt was made to describe the processes and parameters involved in the formation, movement and transport of nitrate ions in the soil / groundwater system and also the effects of climate change on the N cycle and groundwater nitrate pollution.

Finally, based on the climate change scenarios for the Mediterranean region and Greece, this paper reviews the potential impacts of climate change on groundwater nitrate pollution in this region.

2. METHODOLOGY

In this paper the foreign and Greek literature was reviewed, with the aim of examining all the factors and parameters involved in the formation and leaching of nitrates from the soil to groundwater and to give special basis to the possible effects of climate change on the above procedures. For the assessment of the impact of climate change on future nitrate concentrations in groundwater, in the Mediterranean region and Greece in particular, a Source-Pathway-Receptor model was applied to the nitrogen (N) cycle. The model also includes a Driver/Pressure term to express climate change [2].

3. RESULTS AND DISCUSSION

3.1. The presence of NO_3^- in groundwater

The most important N-related reactions are of biochemical nature and are determined by either microorganisms or enzymes. For this reason, the impact of nitrates on groundwater should be examined through the biochemical cycle of N (Fig. 1).

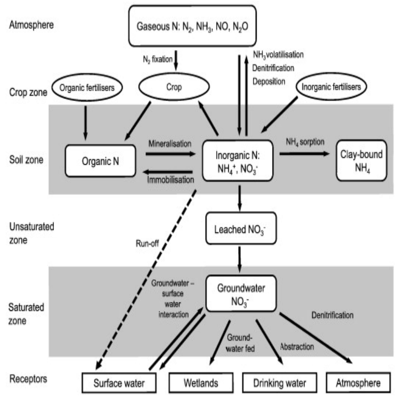

Figure 1. Simplified nitrogen cycle highlighting soil processes [2].

The main process of NO_3^- formation is the nitrification of NH_4^+ ions, while denitrification removes N from the system in the form of N gas, acting as a natural recovery mechanism, by reducing NO_3^- [3]. However, the disruption that has occurred in the N cycle, due to human activities and mainly from agriculture, has resulted in the creation of serious environmental impacts on a global scale [4].

3.1.1 Factors affecting the leaching of NO_3^- into the soil / groundwater system

The main factors that affect nitrate leaching are: i) climate, seasons and irrigation, ii) soil, iii) land uses and iv) inorganic fertilizers, organic manure and waste. The different land uses follow the ranking bellow, in terms of the possible contribution to nitrate loss: forests<cut grassland<grazed grassland, arable cropping<ploughing of pasture< horticultural crops [1].

3.1.2 Nitrate depletion processes

The main processes of NO_3^- reduction in the soil zone are microbial denitrification, volatilization of ammonia and uptake by plants, while in the aquifer the nitrates are subject to three processes: denitrification, DNRA and dilution [5].

3.2 Impacts of climate change on the N cycle

Climate change is expected to affect key processes involved in the N cycle, namely:

<u>Mineralization of N</u>: The increase of soil temperature and humidity positively affect the mineralization, resulting in increased loss of N

gases (greenhouse gases) and increased leaching of N from soils, with a consequent decrease in relative water quality [6].

<u>Nitrification</u>: The increase of CO_2 in the atmosphere negatively affects the nitrification, as it leads to increased soil water content, through the reduced plant stomatal conductance. Increased N availability has a large effect on nitrification, however when CO_2 increases this positive effect is suppressed [7]. Finally, there is a positive correlation between the increase in temperature and the increase in the rate of nitrification, especially the increase in temperature in winter accelerates the rate of nitrification of organic matter, making winter nitrification as a very important process of the annual cycle of N, between agricultural soils and aquifers [8].

<u>Denitrification</u>: Climate change will directly affect denitrification through changes in soil moisture and temperature, but also indirectly through increasing of atmospheric CO_2 concentration (Fig. 2). Elevated CO_2 levels can lead to an increase in soil moisture and C substrates, thus stimulating denitrification. Increasing the temperature, provided C and NO_3^- sources are available, will have a positive effect on denitrification. Future increases in the duration and intensity of periods of drought and subsequent periods of re-wetting, positively affect the process in riparian areas, which are generally considered "hotspots" of soil denitrification [9].

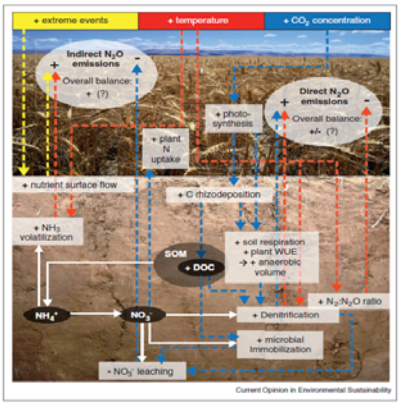

Figure 2. Feedback mechanisms of extreme events, increased temperature and elevated atmospheric CO_2 concentrations on denitrification [9].

However, denitrification will not only be affected by the direct effects of climate change, but also by the indirect effects associated with changes in climate composition, land use and management (Fig. 3) [9].

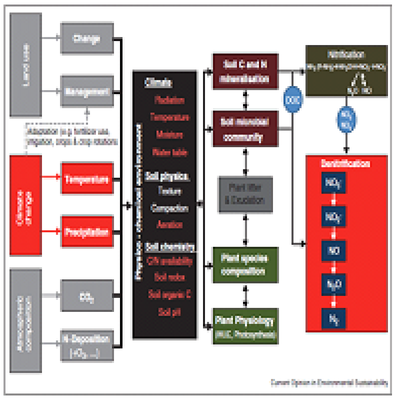

Figure 3. Pathways, mechanisms and processes involved in climate change effects on denitrification [9].

3.3 Climate change and impacts on groundwater nitrate pollution

3.3.1 Potential effects of climate change on the amount of groundwater

Climate change will affect recharge rates and in turn the depth of the level and the amount of available groundwater [10,11]. Changes in storm time arrival distributions or in duration of intermediate periods may affect recharge rates. Precipitation shifts in warmer seasons, with higher evaporation requirements or trends of more frequent drought years, could similarly affect recharge rates [12]. Higher winter temperatures can reduce the amount of ground ice or cause snow to melt and allow more water to seep into the ground, resulting in increased groundwater recharge [11]. Increased aquifer recharge will increase groundwater levels in winter, while in spring and summer they may decrease with a warmer climate recharge [11,13]. Increased concentrations of atmospheric CO_2, in addition to the effects due to rising temperatures, also cause changes in plants, through "CO_2 fertilization". Plants open leaf stomata less, thus reducing evapotranspiration and increasing land runoff [14].

3.3.2 Potential effects of climate change on groundwater quality

Changes in groundwater quality depend on changes in recharge patterns and land use. Reduced soil frost, due to rising temperatures, can increase groundwater recharge, but also the risk of nitrate leaching during winter [15]. Also, nitrate leaching increases with increasing rainfall during the wet season, while an increase in temperature results in a reduction in leaching, due to greater growth and N uptake by plants [16]. The area of high groundwater vulnerability in Europe is expected to increase in the future. These changes in Southern Europe are mainly controlled by climate change, in contrast to Northern Europe where they are controlled by land use changes [17].

3.4 Impact of climate change on groundwater nitrate pollution in the Mediterranean region

3.4.1 Climate change and the nitrogen source term

The Mediterranean region has been recognized as one of the most important "hotspots" in future projections of climate change. Nitrates in the Mediterranean region come mainly from agricultural activities [18,17]. Figure 4 summarizes the ways in which increasing greenhouse gases could have an impact on agricultural nitrate leaching.

Figure 4. Interrelationship of impacts of climate change on soil nitrate available for leaching from agricultural area [2].

Changes in crop yield and distribution: Climate change, through changes in temperature and rainfall, implies changes in the use and management of agricultural land. For Southern Europe and the Mediterranean region, climate change is expected to have a negative impact, with lower yields, higher yield variability and a reduction in areas suitable for the production of traditional products [19].

In summary, the impact of climate change on agriculture is likely to be more severe in the southern Mediterranean region than in the northern temperate regions [20]. Particularly for Greece, the less negative to positive effects of climate change become more intense as we move north and east, with the result that the zones of Eastern Macedonia-Thrace and Western-Central Macedonia are considered more favored or less damaged, depending on case [21].

Effects on leaching N from agricultural land: In Mediterranean cropping systems, nitrate leaching can occur either in irrigated areas or can be associated with rainfall during the wet season [22]. Due to climate change in the Mediterranean region, the frequency and intensity of extreme rainfall is expected to increase in the future, especially during the wet period of the year. This will result in larger amounts of drainage water and consequently increase the risk of groundwater pollution [23]. Projections for reduced rainfall and available surface water for irrigation in the summer, as well as rising temperatures in the summer, will lead to greater pressure to meet the increased irrigation needs of crops from groundwater. This results in a reduction in groundwater feedback rate and depletion of water table, preventing dilution and thus increasing nitrate concentration. In most coastal areas of the Mediterranean, irrigation is done with brackish water, requiring periodic leaching of salts from the soil. Therefore, the increased use of groundwater for irrigation will increase the risk of leaching nitrates [24].

Leaching from forests and upland areas: The increasing risk of fire in forest ecosystems, due to climate change [20], can cause increases in the loss of nitrates from the soil (through leaching and surface runoff) [25,26].

3.4.2 Pathways

There must be a possible path for nitrates to reach a receptor. When the receptor is groundwater, surface water or groundwater dependent ecosystem, an important driver is the amount and distribution of recharge (Fig. 6) [2].

Impact of climate and land use change on recharge and resources: For the Mediterranean region and Greece in particular, a reduction in recharge and water levels is projected in the coming decades, due to reduced precipitation and increased temperature and evapotranspiration, with an enhanced contrast between wet and dry periods. Climate change will lead to greater pressures to meet the increased irrigation needs of crops from groundwater, due to the reduction of surface water used for irrigation [21,20]. A change in cultivation methods or the introduction of new crops can also change soil moisture and recharge [2].

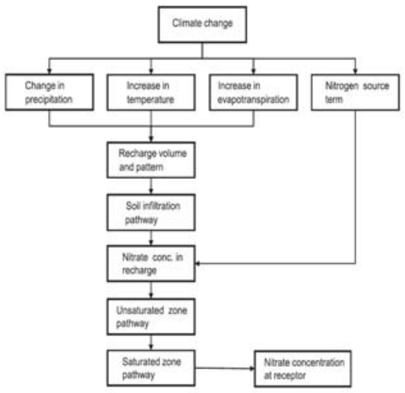

Figure 6. Routes for climate change impact on nitrate leaching pathways [2].

Changes in infiltration through soils: In clay soils, which swell / shrink when a change in water content occurs, the impact of climate change may be increased cracking in more frequent or prolonged dry periods and increased infiltration during more frequent, heavy rainfall [2].

Impact of aquifer pathways on nitrate transport: The region of Southern Europe has aquifers consisting of limestone and karst rocks as well as aquifers of the type "sands and gravels". The former are highly productive, as cracks provide openings for water storage and transport. The karst features develop from cracks or fissures in pure carbonate rocks [17,27]. For fissured aquifers, a marginal increase in winter recharge could occur in the northern part of the Mediterranean basin [28]. Due to the susceptibility of "karst" to pollution, there is a risk of deterioration of the quality of water systems [21]. "Sands and gravels" type aquifers, due to their thickness and high water permeability, form productive aquifers [27]. However, alluvial and shallow aquifers are particularly vulnerable to nitrate pollution [29].

3.4.3 Receptors

Factors that may be involved in the relationship between groundwater nitrate concentrations and receptor concentrations are the relative quantity and quality of water exchanged between groundwater and surface water. Any effects on climate change, which effectively increase the leaching of nitrates to groundwater, could therefore have very serious effects on other receptors, such as groundwater-dependent wetlands, on an annual basis [2].

3.4.4 Limitations on this approach

The simple and linear Source–Pathway–Receptor approach derived from the N cycle does not deal adequately with interactions between the elements in a number of important respects [2]:

● it assumes that the Source, Pathway and Receptor are independent;

● it does not allow the relative significance of the impacts to be assessed, for example an increase in N leaching is not necessarily of importance if the recharge increases such that the concentration of N in the recharge decreases;

● it also does not allow for other feedbacks in the system such as the contribution of N from surface water to groundwater during interactions;

● it does not allow for changes in the route of removal of N from soils directly to surface water thus not impacting on groundwater.

However we believe that it provides a valuable framework to allow the individual elements of this complex system to be assessed.

4. CONCLUSIONS

Groundwater nitrate concentrations are already a serious problem, with many groundwater abstractions containing nitrate concentrations in excess of the drinking water limit. Climate change will affect the hydrological cycle, with an overall decrease in recharge and a drop in water level and an increased seasonal fluctuation of water levels between wet and dry periods. Climate change will also affect the N cycle, as well as agricultural productivity. For the Mediterranean region and Greece, climate change is expected to have a negative impact on agricultural production. Under climate change scenarios and current agricultural practices, nitrate concentrations are projected to continue to rise.

A key issue in assessing future impact in groundwater nitrates is the uncertainty factor arising from:

● uncertainties in future climate and land use projections, as well as difficulties associated with modeling the complex set of processes that can affect groundwater recharging, storage and discharge [12]

● uncertainties of future policy, social values and economic processes, shaping the landscape over aquifers and groundwater demand, including adaptation feedback [30]

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