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Review

Dynamics and emissions of N_2O in groundwater: A review

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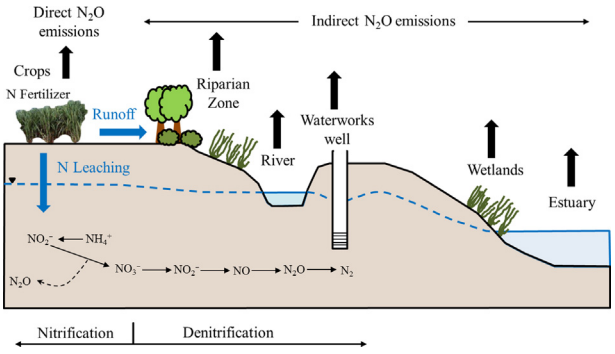
HIGHLIGHTS

- The dynamics and the emissions N_2O in groundwater (GW) are reviewed.
- N-inputs in agricultural areas are the major anthropogenic source of N_2O in GW1.
- Aquifers can accumulate significant amounts of N_2O in shallow GW.
- Denitrification is the main process that produces N_2O followed by nitrification.
- GW N_2O emissions seem to be a minor contributor to atmospheric N_2O emissions.

GRAPHICAL ABSTRACT



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ABSTRACT

This work reviews the concentrations, the dynamics and the emissions of nitrous oxide (N_2O) in groundwater. N_2O is an important greenhouse gas (GHG) and the primary stratospheric ozone depleting substance. The major anthropogenic source that contributes to N_2O generation in aquifers is agriculture because the use of fertilizers has led to the widespread groundwater contamination by inorganic nitrogen (N) (mainly nitrate, NO_3^-). Once in the aquifer, this inorganic N is transported and affected by several geochemical processes that produce and consume N_2O. An inventory of dissolved N_2O concentrations is presented and the highest concentration is about 18.000 times higher than air-equilibrated water (up to 4004 μg N L^{-1}). The accumulation of N_2O in groundwater is mainly due to denitrification and to lesser extent to nitrification. Their occurrence depend on the geochemical (e.g., NO_3^-, dissolved oxygen, ammonium and dissolved organic carbon) as well as hydrogeological parameters (e.g., groundwater table fluctuations and aquifer permeability). The coupled understanding of both parameters is necessary to gain insight on the dynamics and the emissions of N_2O in groundwater. Overall, groundwater indirect N_2O emissions seem to be a minor component of N_2O emissions to the atmosphere. Further research might be devoted to evaluate the groundwater contribution to the indirect emissions of N_2O because this will help to better constraint the N_2O global budget and, consequently, the N budget.

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Contents

1. Introduction

Nitrous oxide (N_2O) is an important greenhouse gas (GHG) and the primary anthropogenic stratospheric ozone depleting substance (Turner et al., 2015). GHGs are necessary for life because they absorb and re-emit infrared radiation emitted by the Earth's surface and contribute to maintain heat in the atmosphere. However, the current atmospheric concentrations of N_2O are 19% higher than those during the preindustrial era, reaching 323 ppb (vs. 270 ppb) (WMO, 2010). This increase has enhanced the heat-trapping capability of the atmosphere causing undesirable effects such as global warming (IPCC, 2014).

Globally, about 40% of total N_2O emissions come from human activities such as fossil fuel combustion, industrial activities and agriculture (Fig. 1) (Syakila and Kroeze, 2011). Agriculture is the largest contributor to the global anthropogenic N_2O budget (Buckingham et al., 2014; Reay et al., 2012; Smith et al., 2007). Agricultural N_2O emissions are divided into two categories: direct emissions (from soil to the atmosphere) and indirect emissions, resulting from nitrogen (N) inputs from

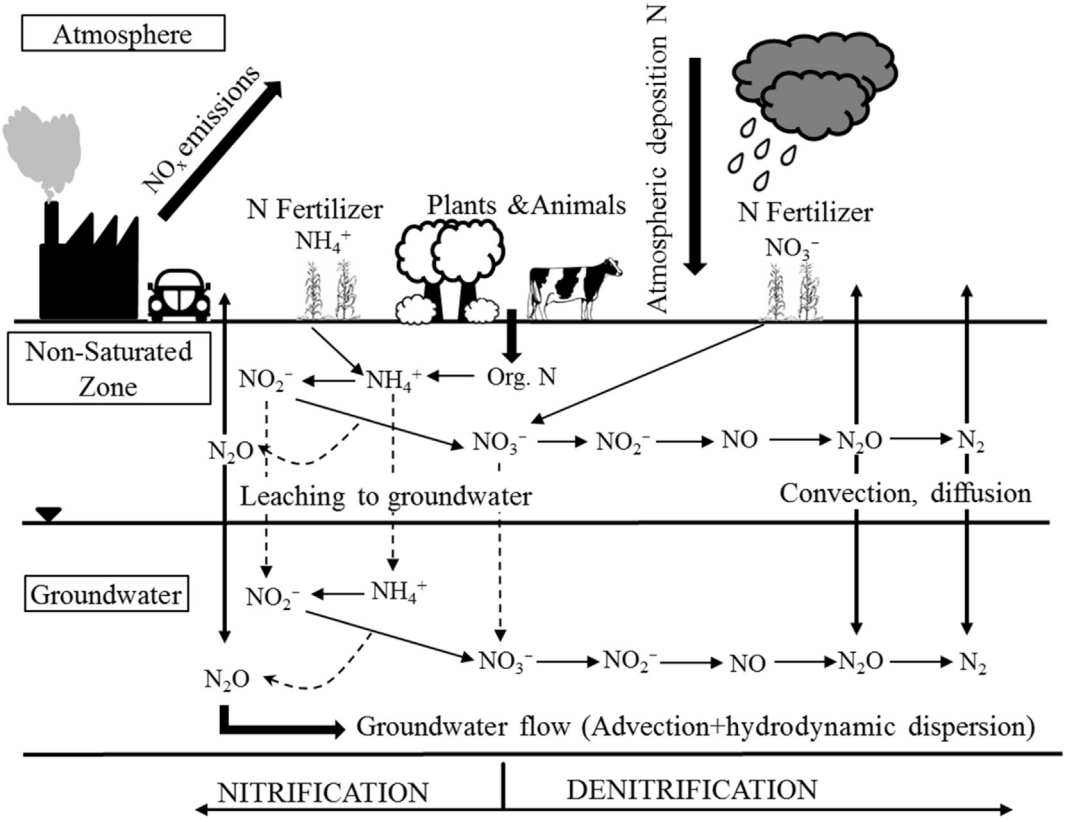

Fig. 1. The global nitrogen (N) cycle is driven by the fixation of atmospheric N and the formation of reactive compounds such as ammonium (NH_4^+), nitrate (NO_3^-) and nitrous oxide (N_2O). Anthropogenic sources include the use of fertilizers, fossil fuels combustion and industrial activities. Note that the main processes (denitrification and nitrification) that contribute to the production of N_2O are also represented.