



# Nitrate behavior in a groundwater flow system that discharges into the largest lakes of Mexico



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## Introduction

The Cuitzeo Groundwater Flow System (GFS) is located in central Mexico, within a volcanic arc, and comprises the second and third-largest lakes in the country. and is one of the most agriculturally developed areas. The GFS is composed of different components or flow paths, with the local component being the most abundant. Particularly within this component, maximum nitrate concentrations of 70.44 mg/L NO<sub>3</sub><sup>-</sup> were recorded for 2024 and 108.53 mg/L for 2025. A total of 11 sites exceed the Mexican standard that establishes permissible limits for drinking water quality (11 mg/L as N-NO<sub>3</sub>) (DOF, 2017); however, the source of these concentrations has not yet been determined. The objective is to analyze the nitrate behavior in groundwater and lake waters to understand the spatial changes over two years.

## Methodology

- Fieldwork during the dry seasons of 2024 and 2025: 39 sampling sites including wells, springs, and hand-dug wells.
- Laboratory analyses (major ions and trace elements)
- Office work: hydrogeochemical interpretation using diagrams: Piper and bivariate diagrams of the relationship between NO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup>, and Na<sup>+</sup> (Yang, 2025).
- Generation of distribution maps and statistical analysis to determine the central tendencies of the data.

## Conclusions

In Figure 1, it can be observed that NO<sub>3</sub><sup>-</sup>-N concentrations were higher in 2025, with the highest values surrounding Lake Cuitzeo. However, according to the permissible limit established by Mexican regulations, several sites across the GFS exceed this threshold. Regarding ammonium (Figure 2) concentrations were also higher in 2025, with the greatest values found around Lake Pátzcuaro. This suggests that nitrogen is undergoing different processes within the system, both in the upper part of the GFS, where Cuitzeo is located, and in the lower part, where Pátzcuaro is situated. In addition, Figure 4 shows the sites that exceed the permissible limits, where the highest concentration recorded is >24 mg/L, more than three times the value established by the standard.

To identify the potential sources of nitrogen, bivariate diagrams were constructed (Figure 5). In both plots (a) and (b), the NO<sub>3</sub><sup>-</sup>/Na<sup>+</sup> and NO<sub>3</sub><sup>-</sup>/Cl<sup>-</sup> ratios indicate a predominant enrichment associated with agricultural activities. However, an enrichment in Cl<sup>-</sup> is also observed, suggesting additional contributions from domestic wastewater discharges.

## Results

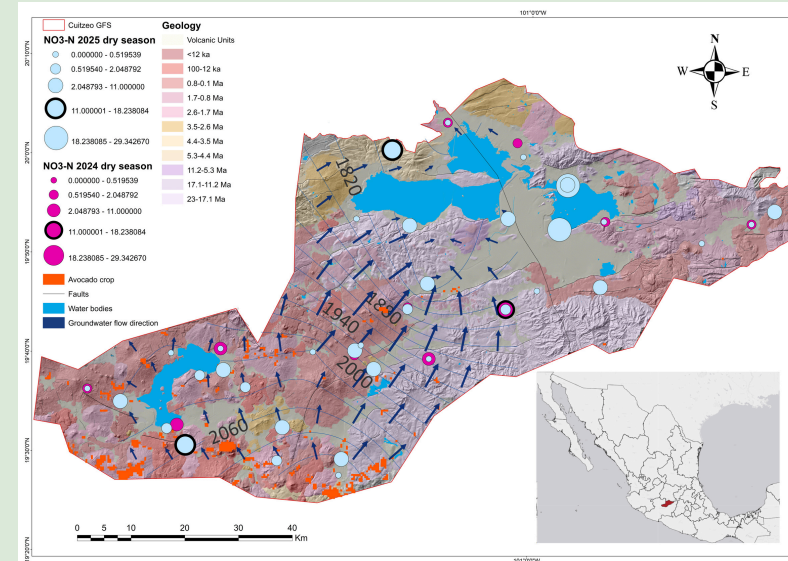


Figure 1. Cuitzeo Groundwater Flow System (GFS). The figure shows the spatial distribution of sampling sites and the concentration of nitrate expressed as NO<sub>3</sub>-N.

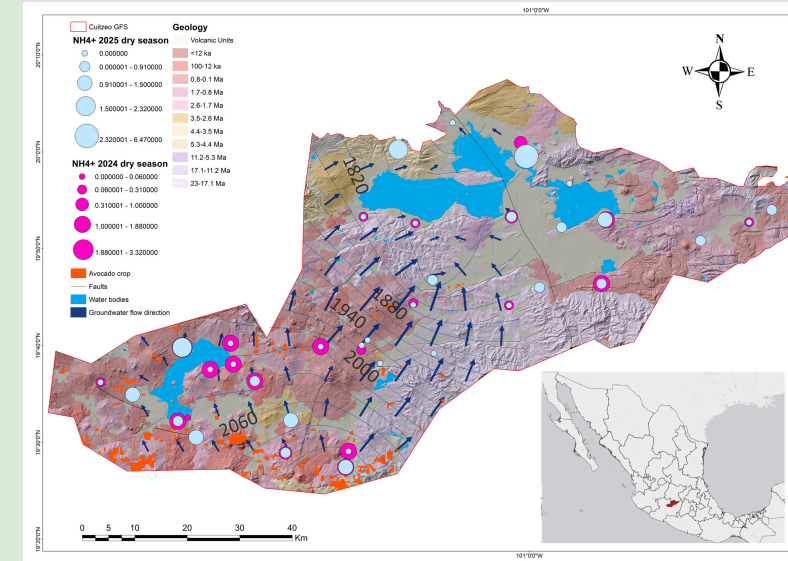


Figure 2. Cuitzeo Groundwater Flow System (GFS). The figure shows the spatial distribution of sampling sites and the concentration of nitrate expressed as NH<sub>4</sub><sup>+</sup>.

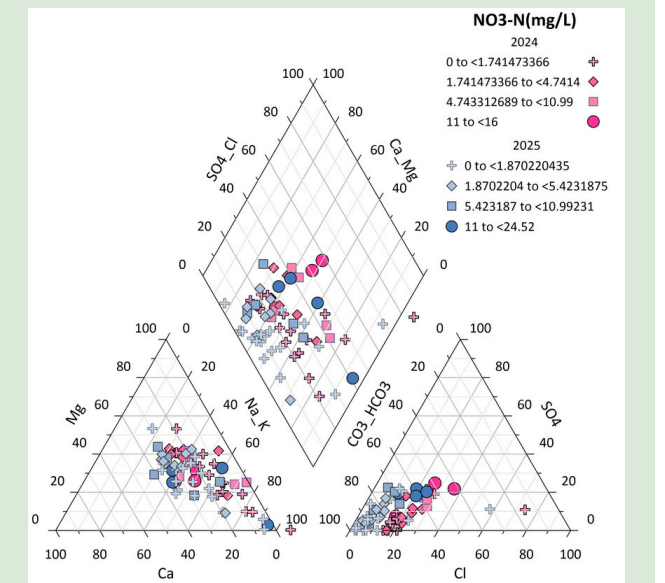


Figure 3. Piper diagram for the Cuitzeo GFS. Pink symbols represent data from 2024, while blue symbols correspond to 2025.

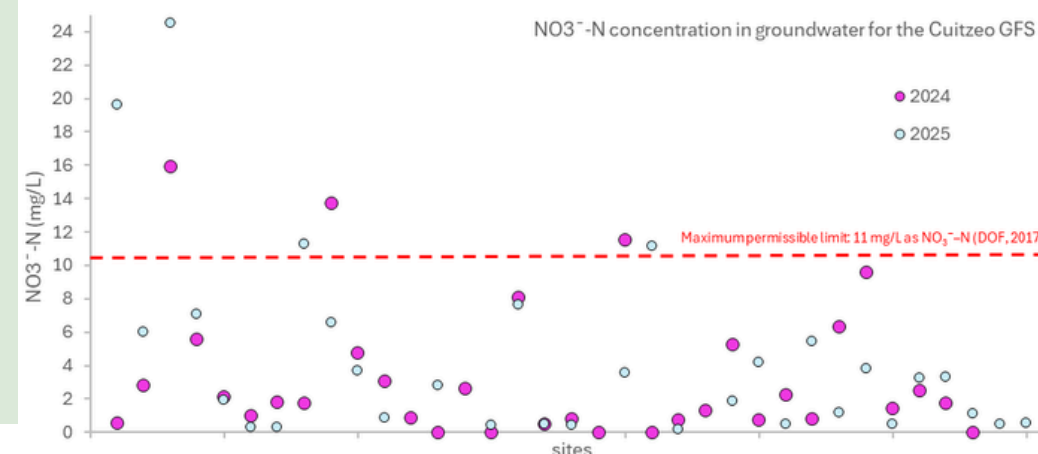


Figure 4. NO<sub>3</sub>-N content for the sampling sites, showing the maximum permissible limit according to Mexican regulations.

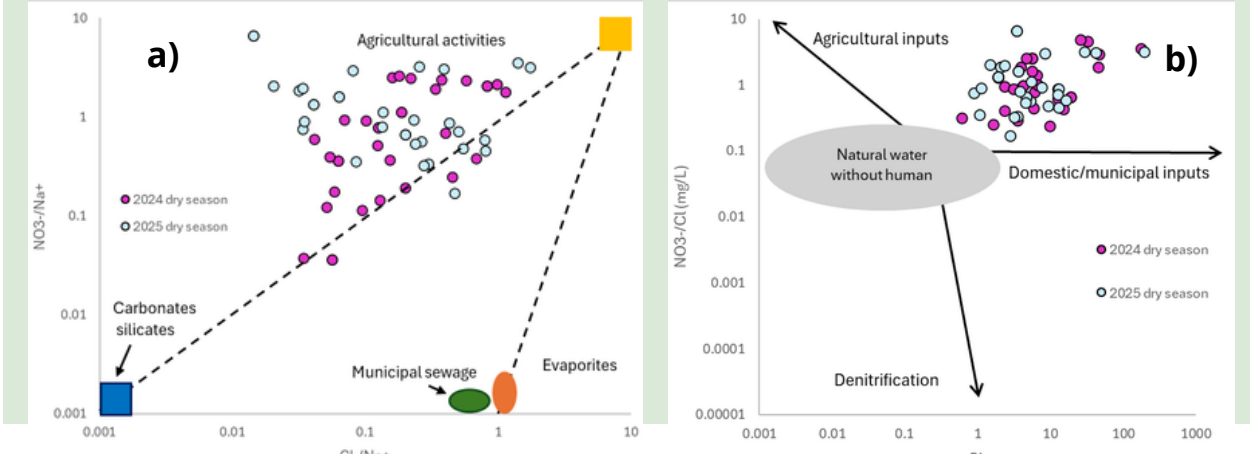


Figure 5. Relationship plots of NO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup>, and Na<sup>+</sup> in groundwater from the Cuitzeo GFS: a) NO<sub>3</sub><sup>-</sup>/Na<sup>+</sup> vs. Cl<sup>-</sup>/Na<sup>+</sup>; b) NO<sub>3</sub><sup>-</sup>/Cl<sup>-</sup> vs. Cl<sup>-</sup>.