

Multi-parameter Analysis of Spatial and Temporal Variability of Groundwater Quality for Optimized  
Water Resource Management: Case Study of Bourgogne-Franche-Comté (France)

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## ABSTRACT

Sustainable management of groundwater resources requires a comprehensive understanding of the processes controlling water quality variability under increasing anthropogenic and climatic pressures. This study proposes an integrated multi-parameter approach to analyze the spatial and temporal variability of groundwater quality at a regional scale, using the Bourgogne-Franche-Comté region (France) as a case study. The methodology is based on the exploitation of a large hydrochemical database (SISE-EAUX), including 22 physicochemical and bacteriological parameters collected from 989 sampling points over a period exceeding five years.

The dataset was processed using multivariate statistical techniques, including Principal Component Analysis (PCA) and Hierarchical Clustering, allowing dimensionality reduction and identification of the main factors controlling water quality variability. A key aspect of this work is the separation of spatial and temporal variability, enabling a better understanding of the mechanisms governing groundwater composition. The results show that groundwater mineralization is primarily controlled by lithological factors, reflecting water–rock interactions and regional geological structures, whereas bacteriological contamination exhibits strong temporal variability linked to seasonal climatic conditions, particularly rainfall events, and anthropogenic activities such as agriculture and wastewater inputs.

The analysis highlights the existence of distinct hydrochemical groups at the regional scale, each characterized by specific geochemical signatures and contamination processes. These groups reflect both natural processes, including redox conditions and mobilization of trace elements, and human-induced impacts, such as nitrate pollution and fecal contamination. The spatial organization of these groups is consistent with geological formations and land use patterns, demonstrating the strong influence of environmental factors on groundwater quality.

This study provides a robust methodological framework for the interpretation of large groundwater quality datasets and contributes to the optimization of monitoring networks by identifying the most relevant parameters and spatial patterns. The results offer practical insights for improving groundwater management strategies and ensuring the protection of water resources intended for human consumption.

**Keywords:** Groundwater quality; Spatial variability; Temporal variability; PCA; Water resource management.