

Project: Control and Prevention System for Contaminants in Mineral-Medicinal Waters through Artificial Intelligence

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INTRODUCTION

Mineral-medical waters constitute the therapeutic foundation of health resort medicine. Ensuring their safety, quality, and stability is paramount, yet conventional monitoring relies on discontinuous sampling, which is insufficient for detecting rapid geochemical or microbiological fluctuations. The AQUAPRED-SUDOE project is a transnational initiative (Spain, Portugal, and France) designed to modernize this sector through a multidisciplinary approach involving physics, medicine, pharmacy, biology, and informatics.

Central to the project is the study of the Hydrobiome—the natural microbial community—and the Hydrogenome, the complete genetic material of these organisms. These biological signatures are deeply influenced by the dynamics and geochemistry of groundwater; for instance, the isolation and age of an aquifer dictate whether the community is dominated by nitrate-utilizing microorganisms (recent water) or those involved in the redox cycles of iron and sulfur (older water).

OBJECTIVES

Implement real-time monitoring of fundamental water parameters

Characterize the hydrobiome and hydrogenome to understand the microbial "fingerprint" of thermal waters

Develop Machine Learning (AI) models to predict contamination events and optimize energy efficiency

Provide a digital framework for sustainable management in European thermal regions

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MATERIALS & METHODS

Methodology: Sensor Network and Real-Time Monitoring

Custom-designed sensor systems were installed across the entire hydraulic circuit in six pilot locations: Laias (Spain), Dax (France), Chaves (Portugal), El Raposo (Spain), Saubusse (France), and Cofrentes (Spain). The project follows three developmental stages:

Knowledge and Innovation: Designing data capture systems and sensor networks; establishing scale models for initial data acquisition.

Deployment and Measurement: Implementing the monitoring system in real-world thermal environments and evaluating predictive performance.

Health Security and Quality Increase: Defining parameter ranges and rules of action to establish a predictive prevention strategy.

Data Flow: Monitoring → Detection Team → Data Treatment → AI Analysis → Quality Adjustments → Optimization of Thermal Water Quality.

Methodology: Hydrobiome and Hydrogenome Analysis

To capture spatial variability, samples are collected from the origin/collection points, storage tanks, and therapeutic treatment points. This allows the project to detect microbiological shifts within the distribution circuit.

This approach specifically aims to characterize the "idiosyncrasy" of each water source and assess seasonal variability between spring and autumn campaigns

RESULTS & DISCUSSION

1) Results: Seasonal Variations and Microbial Signatures

A critical finding of the project is the distinction between microbial stability and environmental influence based on depth. Microorganisms located in intermediate soil layers remain relatively stable, whereas those in surface and subsurface layers are significantly affected by seasonal hydrological and geochemical cycles.

Taxonomic Profile: The predominant phyla identified are Proteobacteria, Firmicutes, and Deinococcus-Thermus. These groups play vital roles in biogeochemical cycles, including Sulfur, Nitrogen, and Methane, which directly influence the mineral content and quality of the water.

Temporal Extensions: Significant variations observed in 2024 have justified the extension of monitoring into 2025 and 2026 to ensure the AI models are trained on comprehensive seasonal data.

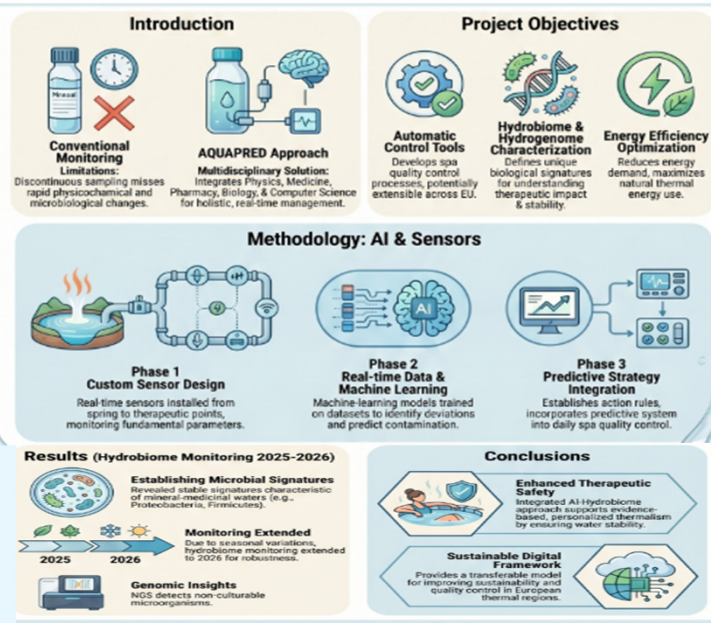
2) Results: AI Model Performance and Energy Efficiency

The integration of real-time sensor data with hydrobiome signatures has enabled:

Anomaly Detection: Successful real-time outlier detection for time series, identifying deviations from established baseline behaviors.

Actable Rules: Development of specific rules of action when parameters fluctuate outside of safe therapeutic ranges.

Energy Circularity: Energy-efficiency models have successfully reduced operational demand by maximizing the use of residual thermal energy, promoting environmental sustainability.



CONCLUSION

The AQUAPRED-SUDOE project demonstrates the feasibility of integrating AI and hydrobiome science to transition toward "personalized thermalism." By associating specific microbial and mineral profiles with clinical conditions—such as rheumatic, respiratory, or dermatological disorders—the project provides a rigorous scientific basis for thermal treatments. Furthermore, the project establishes a transferable digital framework that supports the EU Research and Technological Development Policy, ensuring the sustainable management and environmental protection of European thermal

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