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Advanced and integrated multiparametric tool for proactive and continuous environmental monitoring and control of surface water bodies in sensitive areas

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Abstract Surface water bodies (SWBs) play a crucial role in preserving biodiversity and supporting global environmental health. However, they are increasingly threatened by anthropogenic pressures such as water withdrawals, pollutant discharges, and land-use changes. Currently, there is no globally standardized, integrated approach for continuous environmental monitoring of SWBs in protected areas. Existing methods are typically fragmented, focusing on isolated environmental parameters or assessing the impacts rather than the causes. The research presents an innovative, multiparametric, and proactive monitoring framework specifically designed for SWBs in sensitive and protected areas. The proposed methodology aims to enable continuous assessment and control of environmental pressures, thereby supporting both ecosystem protection and informed decision-making. The framework is structured into five phases, combining the DPSIR (Driving forces–Pressures–State–Impacts–Responses) conceptual model with the Deming Cycle (PDCA – Plan, Do, Check, Act), ensuring an adaptive and systematic approach.

Experimental analyses were conducted on a real case study of a representative stretch of the Calore river, located in the Cilento Park (province of Salerno, Campania Region, Italy), in order to validate the proposed method. Preliminary findings from the contextual analysis highlight a strong ecological and touristic value of the area. The application of the proposed methodology demonstrated its effectiveness as a proactive management tool, facilitating sustainable development and improving ecosystem resilience. The approach represents a significant step toward integrated, proactive, data-driven water resource governance in protected environments.

Keywords: Environmental monitoring, Ecosystems, Environmental pressure, Water management, Sustainable Development

1. Introduction

Environmental monitoring of surface water bodies (SWBs) in protected areas is a pivotal tool for the protection of ecosystems and sustainable management of natural resources (Bellino et al., 2020). Currently, the approaches in scientific literature mainly focus on assessing the effects of environmental pressures to determine water quality status, rather than identifying the underlying causes of ecosystem degradation (Naddeo et al., 2005, 2023). This framework limits the effectiveness of conservation strategies and proactive management (Akthar et al., 2021). The research presents and discusses an advanced and integrated multiparametric methodology for the environmental monitoring of SWBs in protected areas with the aim to assess the potential cause of negative and significative effects in terms of water quality. The proposed methodology provides a systematic proactive quantification of the potential pressures, in order to prevent negative effects on the SWBs ecosystem. At least an environmental sustainability class of the SWB is defined. The research promotes a proactive and cause-based tool to support decision makers in the governance of natural water resources, in order to ensure their continuous protection and valorisation.

2. Materials and methods

2.1. Methodology

The proposed methodology is based on an Initial Context Analysis (ICA), which provides the current state of the art of the SWB. This initial step focuses on the characterization of the environmental, territorial and socioeconomic context and related determinants and pressures acting on the ecosystem, according to the DPSIR model. The ICA is followed by 4 phases structured according to the Deming Cycle (PDCA – Plan, Do, Check, Act) and organized on pressures (natural and anthropic) and effects analysis. For the analysis of pressures, an indexing procedure based on a multi-criteria approach and 3 hierarchical levels are adopted: Thematic Areas (TA), Categories (Cat), and Criteria (C). For each criterion (indicator), a specific index scale ranged in an interval of 0-5, for the normalization of the measured value of each indicator, is provided. Whereas the analysis of the effects is carried out by physical-chemical characterization for an initial selection of 264 parameters at different point of the SWB. For the normalization of the effects, the measured values are divided by their respective regulatory limit and/or target value. Therefore, indices for pressures (IPP) and for effects (IEE) are calculated by considering the 75th percentile of the indicators normalized. The effects are categorised into sustainability classes, defined on the basis of the quartile (Q1, Q2, Q3) distribution of IEE values. Table 1 shows the environmental sustainability classes' definition of the SWB.

Table 1. Sustainability class classification of the SWB.

Range of estimated IEE	Sustainability class	Qualitative description
IEE ≤ Q1	High	A stable and balanced ecosystem
Q1 < IEE ≤ Q2	Moderate	A reactive system with potential loss of balance
Q2 < IEE ≤ Q3	Critical	Ecosystem under stress
IEE > Q3	Inadequate	Ecosystem degradation

This approach is mandatory for the first year in order to calibrate the ranges of measured effects with the associated pressure intensity levels, whose classification is directly linked to that of the effects. Drawing on first-year results, a statistical model correlating effects and pressures is developed. From the second year onwards, only pressures will be measured, in accordance with the proactive approach of the proposed methodology; the sustainability class will then be determined on the basis of the correlation of the developed statistical model. To consider environmental dynamics, the procedure requires the calibration of the statistical model at least every two years.

2.2. Experimental analysis – Plan and Programme

The proposed methodology is validated in the context of "Cilento, Vallo di Diano and Alburni" National Park (PNCVDA), located in the southern part of the Campania Region (Italy). This area (UNESCO World Heritage Site and Global Geopark) is known for its distinctive Mediterranean landscape and a complex hydrographic network. The methodology is, in particular, applied to a pilot section of the Calore SWB. The Calore River is characterised by a total length of 70 km and a basin area of 774 km². Figure 1 shows some of the main anthropogenic activities occurring in Calore river's influence area.

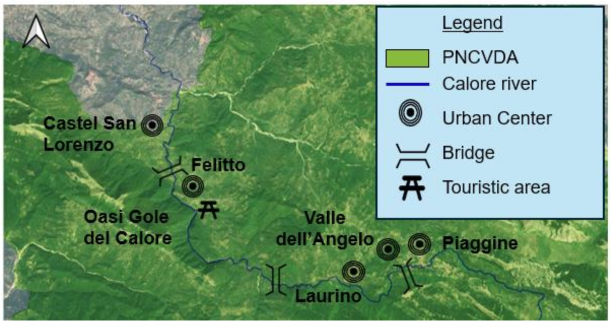

Figure 1. Overview of the activities on the Calore SWB

The experimental pilot section is characterized by the presence of an urban centre and its wastewater discharge. Four monitoring points were identified in order to characterise the effects. While as regards the pressures an area of influence for 50 metres from the riverbank in both directions was analysed.

3. Results and conclusions

Preliminary findings of six-month experimental campaign, highlight that the pressures related to the "anthropic" thematic area are consistent and refer to indicators such as the number of discharges and urban land use. While, with reference to the effects, compliance with limit or target values was detected for the all the investigated 264 parameters. The proposed methodology, based on an advanced and integrated multiparametric tool, enhances the assessment of the environmental sustainability of a SWB within sensitive areas, such as National Parks. This approach is useful for park managers and control authorities, acting as a proactive, continuous, simple and immediate monitoring and control tool of pressures, avoiding effects and related campaigns that require significant efforts and resources, including expensive laboratory determinations and prolonged analysis times.

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