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Optimum selection and placement of agricultural best management practices in Pinios river basin for the mitigation of nitrates water pollution and water scarcity

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Abstract. The intensification of agricultural activities, which are crucial for sustaining crop productivity in rural areas, can also lead to the depletion of water supplies and the degradation of water quality. The challenge of addressing nitrates water pollution and water scarcity at a river basin scale requires the consideration of trade-offs between economic and environmental targets. The adoption of Best Management Practices (BMPs) in agriculture to deal with the issue is becoming increasingly widespread. This study implemented the Soil Water Assessment Tool (SWAT) model to evaluate nitrates discharges and water conservation in response to alternative agricultural management practices. The model was embedded within a decision support tool, enhanced by a multi-objective optimization algorithm to analyze the alternatives, suggesting the most efficient allocation of BMPs to address the above-mentioned water objectives at a basin scale. Applying a four-objective optimization process, various mitigation strategies, including individual and combined changes in livestock and farming practices, were examined in Pinios river basin, proving the methodology's resilience and relevance. Through the use of cost-efficient measures, modelers can identify and prioritize appropriate management strategies by combining process-based hydrological models with fast and precise cost estimations.

Keywords: BMPs, optimization, SWAT, water quality, water quantity

1. Introduction

The intensification of agricultural activities has been essential for maintaining local economies and increasing food production. However, in rural catchments, the extensive use of conventional farming practices is closely associated with the qualitative and quantitative degradation of water bodies. The discharge of nitrates into surface water is one of the most serious environmental issues in such areas, since it can negatively impact the ecosystem's health. Furthermore, the high-water requirements of agriculture put additional pressure on the limited freshwater supplies, particularly in semi-arid and Mediterranean areas (Panagopoulos et al., 2014). The European Union has been addressing the accumulation of nutrients in aquatic systems since the early 1990s with a comprehensive legislative framework, mainly through the Nitrates Directive (91/676/EEC), which targets diffuse pollution. The Water Framework Directive (2000/60/EC) was further created to integrate water management at the river basin level, along with changes to the Common Agricultural Policy (CAP) and initiatives under Rural Development Programs to encourage Good Agricultural Practices (GAPs) and procedures connecting subsidies to environmental conservation (Bouraoui and Grizzetti, 2014). In Greece, River Basin Management Plans and designated Nitrate Vulnerable Zones with supplementary Action Programs have been used to incorporate these instructions into national law. However, improvements in water quality are still inadequate due to gaps in stakeholder engagement and slow environmental response. Within this complex condition, the aim of this study is to optimize the spatial allocation of Best Management Practices (BMPs) supported by the above-mentioned action programs.

2. Material and Methods

Pinios river basin covers almost entirely the river basin district of Thessaly, which is located in central Greece and is one of the most important agricultural producers of the country. The intensive cultivation of cotton, wheat and corn is the main source of high agricultural water demand and severe nitrate pollution, placing the basin within the designated Nitrate Vulnerable Zones. The Soil and Water Assessment Tool (SWAT), a semi-distributed, process-based hydrological model (Aloui et al., 2023), was utilized to simulate the basin-scale hydrological processes, crop growth and nutrient transport for the years 2016–2023. The simulated results confirm the success of the simulation when compared with the observed data (Sismanidi et al., 2025). Several BMPs were implemented in the calibrated model for the main crops and livestock to simulate and evaluate the decreased water consumption and nutrient losses. These BMPs included reduced fertilizer application, precision irrigation, the installation of cover crops used as green manure and a combined practice of fertilizer reduction and deficit irrigation. For livestock management, a reduction of livestock stocking rates and a decrease in the length of the grazing season in pastureland, avoiding the wet months, were employed.

To evaluate the economic feasibility of these practices, the producers' annual net income was estimated, taking into account the input changes under each management approach. The total amount of nitrates and irrigation water consumption was also calculated per simulated scenario. After the economic analysis, a Decision Support Tool was created to identify the optimal strategies to mitigate the degradation of water quantity from irrigation withdrawals and surface water quality from nitrate pollution, both of which can preserve agricultural income and yields. This tool combines the hydrological model with the multi-objective GA NSGA-II, which is embedded into MATLAB's Global Optimization Toolbox. The algorithm explores the most efficient management strategies at the basin scale by searching through countless combinations of BMPs across agricultural lands.

3. Results

The optimization analysis demonstrated trade-offs between irrigation water consumption, nitrate-nitrogen ($N\text{-}NO_3$) loads, and producers' annual total net income as shown in Figures 1 and 2. GA is by default attempting to minimize every criterion, resulting in net income being estimated with a negative sign. The implementation of BMPs reduced water demand and nitrate losses, while having some effect on farmers' net income, which resulted in considerable environmental benefits.

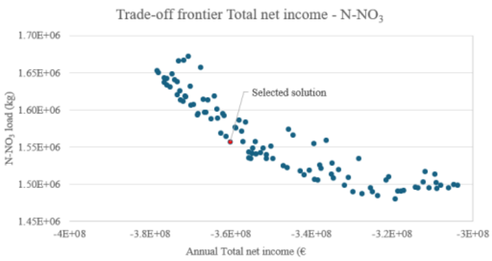

Figure 1. Trade-off frontier between net annual income - NNO_3.

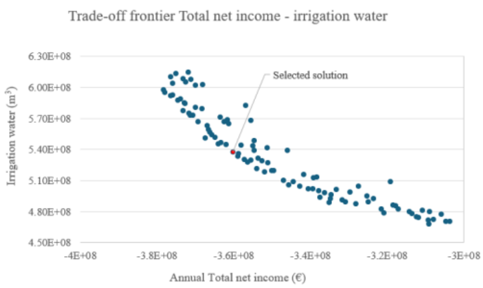

Figure 2. Trade-off frontier between net annual income - irrigation water.

The selected solution, depicted in Figure 3, maintains the total annual net income and yield while enhancing water quality and quantity. Specifically, nitrate loads and irrigation water consumption were reduced by 14% and 25%, respectively. A variety of alternatives can be observed by the trade-off curves, demonstrating the potential of enhancing resource efficiency and water quality without significantly affecting profits. In some cases, even a slight increase in total net income is also evident. These findings demonstrate that, at the basin scale, water quality and resource sustainability can be improved by even slight, spatially oriented interventions.

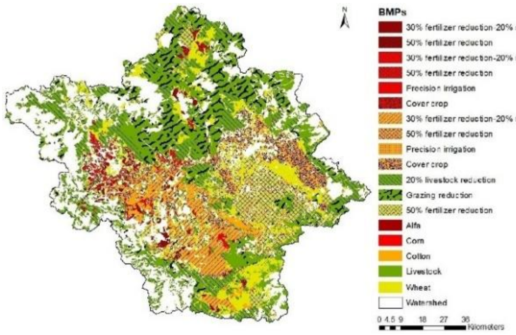

Figure 3. BMP allocation of a compromise solution.

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References

Aloui, S., Mazzoni, A., Elomri, A., Aouissi, J., Boufekane, A., & Zghibi, A. (2023), A review of Soil and Water Assessment Tool (SWAT) studies of Mediterranean catchments: Applications, feasibility, and future directions. Journal of Environmental Management, **326**, 116799.

Bouraoui, F., & Grizzetti, B. (2014), Modelling mitigation options to reduce diffuse nitrogen water pollution from agriculture. Science of the total environment, **468**, 1267-1277.

Panagopoulos, Y., Makropoulos, C., Gkiokas, A., Kossida, M., Evangelou, L., Lourmas, G., ... & Mimikou, M. (2014), Assessing the cost-effectiveness of irrigation water management practices in water stressed agricultural catchments: the case of Pinios. Agricultural water management, **139**, 31-42.

Sismanidi, M., Kokkinaki, L., Kavalieratou, S., Georgoussis, H., Giannoulis, K. D., Dimitriou, E., & Panagopoulos, Y. (2025), Assessing the Effects of Bioenergy Cropping Scenarios on the Surface Water and Groundwater of an Intensively Agricultural Basin in Central Greece. Hydrology, **12(4)**, 66.