



SWAT modelling to unveil and manage the impact of diffuse and point source pollution within Adige River basin

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The Soil and Water Assessment Tool (SWAT) is a widely used hydrological model designed to simulate water flow, sediment transport, and nutrient cycling in complex river basins. This study employs SWAT to assess the impact of both diffuse and point sources of nutrient contamination on river water quality in the Adige River basin, one of Italy's largest and most significant waterways. The Adige River basin presents a diverse hydrological system influenced by agricultural practices, urban development and industrial activities, making it a representative case for evaluating nutrient dynamics and their environmental implications in a complex contest.

Diffuse sources of nutrient pollution, primarily from agricultural runoff, contribute substantially to the nutrient load in the Adige River, particularly nitrogen and phosphorus. These nutrients often originate from fertilizers, animal manure and soil erosion and their impacts are exacerbated by rainfall and irrigation practices. Point sources, such as wastewater treatment plants, industrial effluents, and urban discharge points, introduce localized but often concentrated nutrient loads to the river system. Understanding the interaction between these sources is critical for developing effective management strategies which prioritize interventions to mitigate adverse effects on water quality.

Using SWAT, this study integrates extensive spatial and temporal data, including land use, soil properties, climate variables and hydrological records, to simulate nutrient fate and transport across the basin. The model's ability to account for both diffuse and point sources allows for a holistic understanding of nutrient dynamics and investigating their cumulative and disaggregated impacts on the river. SWAT outputs are validated against observed water quality data, ensuring robust and reliable simulations.

The application of SWAT in the Adige River basin not only highlights the spatial distribution and seasonal variability of nutrient loads but also identifies critical source areas that disproportionately contribute to contamination. By simulating various land-use and management scenarios, SWAT provides actionable insights into how different interventions, such as buffer strips, reduced fertilizer application, or advanced wastewater treatment, can mitigate nutrient pollution. Furthermore, the model supports the identification of nutrient retention and removal hotspots within the river system, enhancing our understanding of the natural attenuation

processes that influence contaminants fate.

The insights gained from SWAT modelling in the Adige River basin have broader implications for water quality management in similar river systems worldwide. The model's comprehensive approach to linking hydrological processes with nutrient dynamics strengthens the knowledge base for addressing diffuse and point source contamination. It offers a scientific foundation for formulating efficient guidelines and policies aimed at reducing nutrient inputs, improving wastewater management, and restoring aquatic ecosystems.

In conclusion, SWAT serves as a powerful tool for understanding the complex interplay between diffuse and point sources of contamination and their effects on river water quality. Its application in the Adige River basin underscores its utility in advancing knowledge about nutrient fate and transport and in guiding targeted, evidence-based strategies to mitigate contamination. This study highlights the pivotal role of hydrological models like SWAT in achieving sustainable river basin management and protecting water resources from the growing pressures of human activities.