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Integrating hydrological modelling and System Dynamics tools for understanding Water-Ecosystems-Food Nexus: hints from the Tarquinia area (Italy)

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ABSTRACT

The present work proposes an operational approach to the concept of Water-Ecosystems-Food Nexus, based on the integration of Participatory System Dynamics Modeling techniques (PSDM) and hydrological modelling, specifically the Soil and Water Assessment Tool (SWAT). Specific reference is made to the Tarquinia Plain area (Central Italy), one of the pilot areas within the LENSES project (PRIMA Foundation, GA n. 2041), where irrigated agriculture plays a vital role for local communities, yet with increasing concerns for the impacts on the state of the environment and for the interplay with water resources availability (due to climate change impacts) and quality. In summary the proposed approach is based on the use of: i) Causal Loop Diagrams (CLD) for an improved conceptual understanding of system state and potential evolution, as well as for the identification of key challenges and leverage points; ii) hydrological modelling (SWAT) for getting a deeper understanding of the main implications of agricultural practices on the state of the area; iii) stock and flow models, for scenario analysis and policy design. The methodological approach is being replicated in several case studies in Europe and beyond.

1. Introduction and objectives

Access to clean water, energy, and food is vital for human well-being and environmental sustainability. In the face of various threats affecting the availability of natural resources, including the impacts of climate change, there is a growing need to understand the complex relationships among these resources. Resources security requires the adoption of 'Nexus' approaches, oriented to minimize conflicts between different sectors while promoting synergies, compared to a silo approach (Wu et al., 2021).

Reducing conflicts related to natural resources availability and use also requires a wider participation of stakeholders. Their engagement helps incorporating knowledge into model construction, tailoring the model to their specific needs, and ensuring accurate representation of the potential consequences of actions. Ultimately, this approach fosters ownership of the modelling results. In this regard, multiple System Dynamics Modelling (SDM) tools, such as Causal Loop Diagrams (CLDs) or stock and flow models, can help better co-define and understand the dynamic behavior of complex Nexus systems (Phan et al., 2021). The coupling of SDM tools with sectoral models (e.g., hydrological models), can help get a holistic perspective on the state of natural resources in complex environmental systems, while also taking into account the relevance of 'soft' elements (such as socio-institutional actions).

The present work proposes an approach based on the use of SDM tools, coupled with a hydrological model (SWAT) to: i) identify the main Nexus challenges of an irrigated area; ii) understand in detail the implications of irrigation and agricultural practices on the state of the environment and on the local development; iii) suggest potential leverage points (and actions) to support the sustainability transition of the system. Reference is made to the Tarquinia plain area (Italy), one of the case studies of the LENSES project (PRIMA Foundation, GA n. 2041).

2. Methods

The proposed approach proposes the integration of three main tools, as summarized in the following:

1. CLDs have been used to support the conceptualization of the 'Nexus' in the area. Baseline analyses and participatory activities have been coupled in order to get a detailed – and consensual - understanding of the main interdependencies among sectors over the area. In particular, semi-structured interviews have been first performed, to get sectoral perspectives on the system, followed by workshops/focus groups oriented to dive deep into the cross-sectoral connections. Both 'structural' (based on the use of graph theory metrics) and 'descriptive' analyses (based on the analysis of loops) have been performed to identify the main challenges for the investigated system and to preliminarily identify potential leverage points.
2. Based on the key challenge identified in the previous step, i.e. the role of irrigated agriculture in the area and the implications for water resources availability and their state as well as for environmental conditions, the Soil and Water Assessment Tool (SWAT) hydrological model was used. Based on a wide set of available data (including measurements), the model has been calibrated and validated, and then used to assess various components of the hydrological system and to understand the evolution of some key variables related to water quality (such as nutrient load and erosion rate), quantity (runoff, evapotranspiration and infiltration), considering the influence of climate change scenarios.
3. A stock and flow model has been developed to support integrating the evidence from sectoral (including hydrological) models into a holistic picture, supporting the development of a tool to be used for identifying, screening and testing several actions using a Nexus perspective.

3. Results and way forward

The implementation of the methodological approach helped building a consensual view of the area (effectively visualized and shared through CLDs), driving stakeholders towards the identification of consensual Nexus challenges, that can be crucial to guarantee the sustainable development of the area in the next few decades. Some activities (like the participatory mapping) facilitated the dialogue among policy- and decision-makers, and the identification of suitable solutions. The coupling with hydrological modelling was particularly useful in providing deeper technical knowledge on the impacts of irrigation practices on the system under a multiplicity of scenarios, helping to understand also the implications of policies and actions (with a focus on Nature-based Solutions). The development of the stock and flow model (ongoing) will help understand all the implications (including potential side effects) of the selected actions on the system as a whole.

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