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A scenario-based coupled SWAT-MODFLOW decision support system for advanced water resource management

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Abstract

Models provide invaluable visions to decision-makers for basin-scale management of water resources. However, decision-makers have difficulties in directly using these complex models. Water managers are primarily interested in user-friendly features allowing an integration of their judgments into the decision-making process, rather than applying detailed theories and methodologies. This knowledge gap between technical simulation models and policy-makers highlights the urgent need for developing an integrated water resource management decision support system (IWRM-DSS). This paper describes the main aspects of a new IWRM-DSS in which

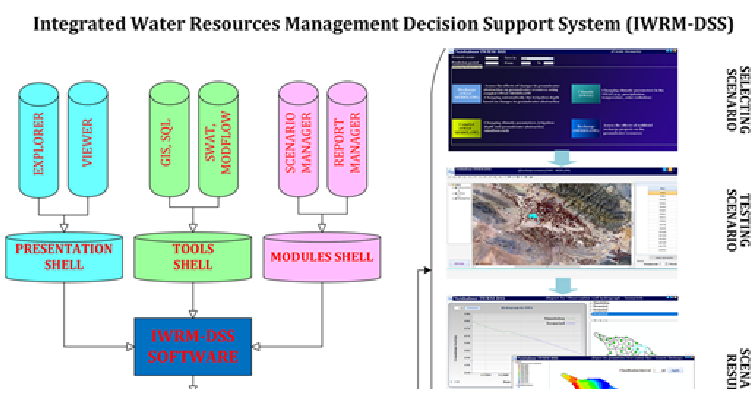
Microsoft Visual Studio under the C# language was employed to integrate the Microsoft SQL server as a database and ArcGIS Engine DLLs for pre/postdata processing for the SWAT and MODFLOW models. Two particular 'module' and 'presentation' shells are specifically designed for decision-makers to create four different scenarios, namely, 'climatic', 'recharge', 'discharge', and 'coupled' and to analyze the results. Decision-makers, without any detailed modeling knowledge and computer skills, can access the data and run models to test different management scenarios in an attractive graphical user interface. The IWRM-DSS, which was applied for the Neishaboor watershed, Iran, reveals that mean annual potential evapotranspiration increased to 8.2%, while runoff and recharge rates are reduced to 35 and 63%, which led to a decline of 13.5 m in mean groundwater level for the 13-year projected period.

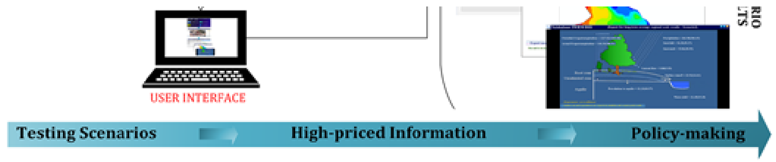
HIGHLIGHTS

- Decision-makers have difficulties in directly using complex simulation models.
- Decision-makers prefer the integration of their judgments into the decision-making process.
- A scenario-based coupled SWAT-MODFLOW Decision Support System was developed.
- Decision-makers can test different scenarios without any detailed modeling knowledge.
- The DSS was efficient to engage stakeholders in the water resource management process.

Graphical Abstract

Graphical Abstract





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Keywords: decision support system, integrated water resource management, management scenarios, MODFLOW, stakeholder engagement, SWAT

INTRODUCTION

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Overexploitation of aquifers in recent decades has led to ever-growing depletion of groundwater resources over time, manifested in declining groundwater levels. Accompanied by climate changes, rapid population, and industrial growth, this issue has exerted pressure on available water resources (Joodavi *et al.* 2017). The use of numerical modeling can enhance an understanding of water resource conditions and sustainability of water resources systems (Izady *et al.* 2017; Joodavi *et al.* 2020). However, most decision-makers cannot directly use the results of the complex simulation and optimization models due to the lack of required knowledge and skills. In fact, the results of scientific research are not always available in the form required by stakeholders and decision-makers (Jacobs 2002; Giupponi *et al.* 2007; Van Kouwen *et al.* 2008). Therefore, developing decision support systems (DSSs) between the developed models and decision-makers is critically important to improve water resource decision-making (Walsh 1993; Parker *et al.* 2002; Liu *et al.* 2008).

The concept of DSSs emerged in the 1970s (e.g. Gorry & Morton 1989; Sprague & Carlson 1982), showing great potential for water resource management. The DSSs are designed to assist in the water resource decision-making process and to enhance usage and understandability of models' outputs. In addition, models incorporated within the DSS framework are often better adapted for decision-making than those models that are designed only for the technical specialist. Indeed, stakeholders in the decision-making process do not delve in the detailed theoretical background of the methodologies applied and prefer user-friendly features, allowing an integration of their judgments into the decision-making process (Walsh 1993).

In the literature, numerous DSSs exist for water resource management, in which increasingly sophisticated computerized systems integrate watershed processes operating at different spatial and temporal scales, simulation models, and decision-making approaches (e.g. Rizzoli & Young 1997; Koutsoyiannis *et al.* 2003; Mysiak *et al.* 2005; Giupponi 2007; Matthies *et al.* 2007; Makropoulos *et al.* 2008; Argent *et al.* 2009; Gastélum *et al.* 2009; Singh 2010; Volk *et al.* 2010; Heidari & Bozorgzadeh 2014; Babbar-Sebens *et al.* 2015; Kumar *et al.* 2015; Tian *et al.* 2016; Wang *et al.* 2016; Mohajeri & Horlemann 2017; Piemonti *et al.* 2017; Aliyari *et al.* 2018; Butchart-Kuhlmann *et al.* 2018; Goharian & Burian 2018; Nohara *et al.* 2018; Ruiz-Ortiz *et al.* 2019; Sarband *et al.* 2020). These DSSs have been developed for a variety of purposes, such as the following: Waterware (Fedra & Jamieson 1996; Jamieson & Fedra 1996), Aquatool for river basin management (Andreu *et al.* 1996), and Nelup, to provide economic and environmental impacts of rural land-use change at the river basin scale (Dunn *et al.* 1996), Floodss for flood management (Catelli *et al.* 1998), Dssipm for irrigation management (da Silva *et al.* 2001), Catchment Simulation Shell for supporting the participatory assessment and management of natural resources (Argent & Grayson 2003), WEAP for integrated water resource management and policy analysis (Yates *et al.* 2005), MULINO-DSS for sustainable use of water resources at catchment scale (Mysiak *et al.* 2005; Giupponi 2007), LADSS for land-use management at farm level (Rudner *et al.* 2007), E2 for water quality modeling (Argent *et al.* 2009), SWASAL to evaluate on-farm irrigation water management options (Singh 2010), WRESTORE (Watershed Restoration Using Spatio-Temporal Optimization of Resources), a web-based participatory planning tool which can involve a large community of stakeholders in using science-based, human-guided, interactive simulation-optimization methods for designing potential conservation practices on their landscapes (Babbar-Sebens *et al.* 2015), IHM3D for integrated SW–GW modeling in which virtual globe-based 3D environment was used to visualize the spatially distributed model inputs/outputs and georeferenced datasets (Tian *et al.* 2016), multi-criteria decision analysis framework for hydrological decision support system (Butchart-Kuhlmann *et al.* 2018), DSS-SMGW-01 to realize sustainable management of groundwater (Aliyari *et al.* 2018), AQUATOOL, with the aim of deepening the consideration of losses by evaporation of reservoirs for a better design of the basin management rules (Ruiz-Ortiz *et al.* 2019), and an interactive spatial DSS for the assessment of water resource allocation scenarios (Sarband *et al.* 2020).

Neishaboor plain is one of the important aquifers in Iran in which groundwater has significant socioeconomic importance, both as a factor of production in agriculture and as a source of drinking water (Nazarieh *et al.* 2018). During the past few decades, this aquifer has experienced severe groundwater depletion and overexploitation which has led to the general prohibition, since 1986, of any further development in this aquifer. Because of such emergent conditions in the Neishaboor watershed, an intensive groundwater and surface water management plan was established by the Khorasan Razavi Regional Water Authority. The plan was initiated by developing a conceptual model for groundwater and surface water in the watershed, as a first step (Izady *et al.* 2014), and was followed by numerical modeling of groundwater and surface water, as a second step, based on the developed conceptual models (Izady *et al.* 2015).

Therefore, the main objective of this study is to develop the integrated water resource management decision support system (IWRM-DSS), as a third step, to support water resource decision-makers to utilize the validated groundwater and surface water models, the outputs of the second step, to assess the long-term effects of different climate, recharge, and discharge scenarios in an attractive

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