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Impacts of climate and land use changes on the hydrological and erosion processes of two contrasting Mediterranean catchments

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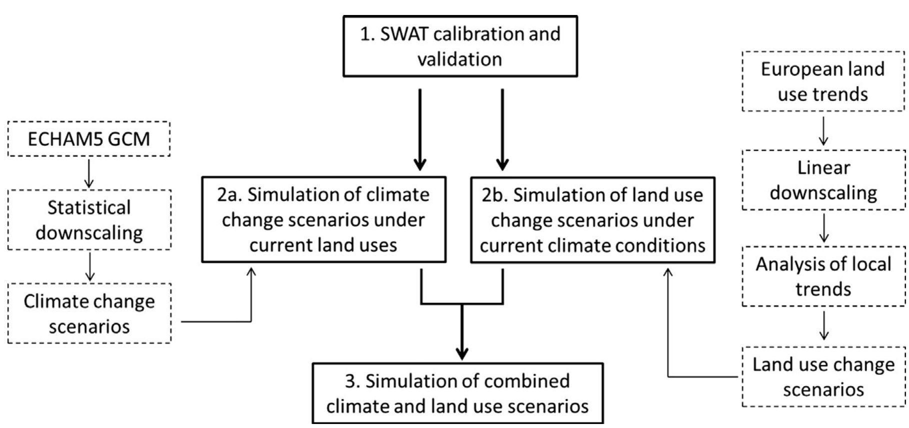
HIGHLIGHTS

- We studied the impacts of climate and land-use changes on streamflow and erosion.
- We compared two Mediterranean catchments with humid and dry climates and landscape.
- Climate scenarios led to a decrease in streamflow in both catchments.
- In the humid site, both scenarios lowered erosion due to permanent vegetation cover.
- In the dry site, both scenarios increased erosion due to perennial vegetation cover.

GRAPHICAL ABSTRACT



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ABSTRACT

The impacts of climate and land use changes on streamflow and sediment export were evaluated for a humid (São Lourenço) and a dry (Guadalupe) Mediterranean catchment, using the SWAT model. SWAT was able to produce viable streamflow and sediment export simulations for both catchments, which provided a baseline for investigating climate and land use changes under the A1B and B1 emission scenarios for 2071–2100. Compared to the baseline scenario (1971–2000), climate change scenarios showed a decrease in annual rainfall for both catchments (humid: −12%; dry: −8%), together with strong increases in rainfall during winter. Land use changes were derived from a socio-economic storyline in which traditional agriculture is replaced by more profitable land uses (i.e. corn and commercial forestry at the humid site; sunflower at the dry site). Climate change projections showed a decrease in streamflow for both catchments, whereas sediment export decreased only for the São Lourenço catchment. Land use changes resulted in an increase in streamflow, but the erosive response differed between catchments. The combination of climate and land use change scenarios led to a reduction in streamflow for both catchments, suggesting a domain of the climatic response. As for sediments, contrasting results were observed for the humid (A1B: −29%; B1: −22%) and dry catchment (A1B: +222%; B1: +5%), which is mainly due to differences in the present-day and forecasted vegetation types. The results highlight the importance of climate-induced land-use change impacts, which could be similar to or more severe than the direct impacts of climate change alone.

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1. Introduction

The impact of changes in climate and land cover on watershed dynamics has been well established worldwide. Among the most important impacts from a watershed management perspective are potential alterations to the hydrological (Bangash et al., 2013; Kalantari et al., 2014; Khoi and Suetsugi, 2014; Luo et al., 2013; Mango et al., 2011; Milly et al., 2005; Montenegro and Ragab, 2012; Mourato et al., 2015; Wilson and Weng, 2011) and erosive response (Bangash et al., 2013; García-Ruiz et al., 2013; Khoi and Suetsugi, 2014; Lu et al., 2013; Vanmaercke et al., 2011; Wilson and Weng, 2011). These changes will in turn affect the ecosystem service functioning of watersheds, such as water provisioning and erosion control (Bangash et al., 2013).

The Mediterranean Basin has been identified as one of the most vulnerable regions of the world to climate change, and the Intergovernmental Panel on Climate Change's Fifth Assessment Report points to projected changes to both the hydrological and erosive response of watersheds due to future shifts in precipitation and temperature regimes (IPCC, 2013). Under the projected climate changes, runoff is expected to decrease (IPCC, 2007, 2013; Nunes et al., 2008) as a result of lower rainfall, higher soil water deficits, and higher potential evapotranspiration (PET) (Molina-Navarro et al., 2014; Nunes et al., 2008, 2013), thereby leading to a decrease in streamflow (Lopéz-Moreno et al., 2011, 2014; Molina-Navarro et al., 2014). As for soil erosion, there is greater heterogeneity in the trends across the Mediterranean Basin, as the processes linking climate and erosion are dependent on a number of variables; including rainfall amount and intensity, soil water content, evapotranspiration, and plant cover (García-Ruiz et al., 2013; Nearing et al., 2005; Nunes and Nearing, 2011).

The magnitude of climate change impacts on hydrological and erosion processes is expected to be strongly influenced by land use/cover, as this driver per se is known to strongly influence these processes (Cerdan et al., 2010; García-Ruiz and Lana-Renault, 2011; García-Ruiz et al., 2013; Nunes and Nearing, 2011). Several studies conducted in the Mediterranean Basin have indicated that the hydrological behavior of different land-cover types is linked to the existing vegetation and to its spatial and seasonal variation patterns (García-Ruiz and Lana-Renault, 2011; López-Vicente et al., 2013; Nunes et al., 2010, 2011). For example, a rise in shrub and forest cover has been reported to produce a decline in surface runoff and streamflow discharge (Beguería et al., 2003; Gallart and Llorens, 2004; García-Ruiz and Lana-Renault, 2011). Land cover also affects soil erosion, as land with permanent vegetation cover (shrub, grassland, or forest) typically has lower soil losses and sediment yields than an arable land (Cerdan et al., 2010; García-Ruiz, 2010).

While it is important to consider the individual effects of climate and land use change on hydrological and erosion processes, assessing how their combined effects will interact is crucial for assessments of the future state of water resources (Hoque et al., 2014; Khoi and Suetsugi, 2014; Li et al., 2004; Li et al., 2009; Li et al., 2012). For the Mediterranean region, only a few modeling studies have addressed the combined effects of these drivers (e.g. López-Moreno et al., 2014; Molina-Navarro et al., 2014). Most studies have focused on the effects of climate change without considering land use/cover change as well (Nunes et al., 2008, 2013; Bangash et al., 2013; Kalogeropoulos and Chalkias, 2013; Zabaleta et al., 2014). Others have only evaluated the impacts of land use changes without considering future climate conditions (De Girolamo and Lo Porto, 2012; López-Vicente et al., 2013; Nunes et al., 2011).

All climate and land use change assessment studies have associated uncertainties in the model results and the selected scenarios (see e.g. Ludwig et al. (2010), for a discussion on this issue). Uncertainties in observed data can mislead model calibration (McMillan et al., 2010; Sellami et al., 2013), and the existence of multiple acceptable model formulations and/or parameterizations can lead to different results for different climate conditions (Beven, 2012; Lespinas et al., 2014). Calibrated model parameters often compensate for shortcomings in the model structure and errors in data (Lespinas et al., 2014). Therefore, uncertainty issues can be partly overcome by restricting possible parameter values through direct measurement, by using multiple observed variables in the calibration process (Beven, 2012; Efstratiadis and Koutsoyiannis, 2010), and by evaluating the model for a large range of climatic conditions (Beven, 2012; Xu and Singh, 2004).

Scenario uncertainties include different projections of socio-economic conditions and greenhouse gas emission (IPCC, 2007, 2013); different response of climate to greenhouse gas concentrations given by different Global Circulation Models (GCMs); different climate downscaling results according to the selection of Regional Climate Models (RCMs) or statistical approaches (Deidda et al., 2013; Maraun et al., 2010); or different land-use scenarios according to different interpretations of future socio-economic conditions (e.g. Stigter et al., in press). The variability between these scenarios for the Mediterranean can lead to quite different projections of hydrological change (Majone et al., in press; Piras et al., 2014; Stigter et al., 2014). To mitigate this issue, a smaller number of future scenarios (or even hypothetical scenarios) can be analyzed to detail particular impacts, becoming in effect a study of sensitivity to climate and land use change (Nunes et al., 2008, 2013; Xu and Singh, 2004).

In this work, the impacts of climate and land use changes on streamflow discharge and sediment export were evaluated both individually, to assess the relative strength of their impacts; and in an integrated manner, to provide a more realistic assessment of future (combined) impacts. This study was performed in two small experimental Portuguese basins (i.e. a paired-catchment approach), one located in a humid region (São Lourenço) and the other in a dry region (Guadalupe). These catchments were selected because: (i) each catchment is representative of the landscapes in their region (i.e. north-western and interior-southern Portugal); (ii) the responses to climate and land use changes are expected to differ in each of these regions due to their contrasting climate, soil, and land cover characteristics; and (iii) the availability of several measured parameters and hydrological variables reduces model uncertainty. A limited number of climate and land use scenarios were selected to evaluate the sensitivity of the study sites to these changes.

The specific objectives of the present study were:

i) To calibrate and validate the Soil Water Assessment Tool model (SWAT) for the São Lourenço and Guadalupe basins;
ii) To simulate the separate responses of stream discharge and sediment export for two scenarios of climate and land use change;
iii) To evaluate the effects of two scenarios combining changes in climate and land use.

2. Methodology

2.1. Study sites

The present work was carried out in two small agro-forested catchments in Portugal. The humid catchment – São Lourenço (6.20 km^2; Coordinates: 40° 25′ 58″N; 8° 30′ 6″W) is located in North Central Portugal (Fig. 1), whereas the dry catchment – Guadalupe (4.49 km^2; Coordinates: 38° 34′ 39″N; 8° 2′ 26″W) – is located in South Eastern Portugal (Fig. 1).

Due to its proximity to the sea, São Lourenço is significantly influenced by the Atlantic Ocean, resulting in mild and wet winters with strong precipitation events and warm and dry summers. The average annual rainfall and temperature in the region (1973–2012) was 925 mm and 15.7 °C (SNIRH, 2014a). Elevations range from 40 m a.s.l. to 100 m a.s.l. and gentle slopes (<5%) dominate the area (Fig. 2). The soils are dominated by Humic Cambisols (50%) with high depth and high organic matter content; with a significant proportion of Chromic Luvisols (23%) and Calcaric